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# Radiological Measurement at the Maxey Flats Radioactive Waste Burial Site 1974 to 1975

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# RADIOLOGICAL MEASUREMENT AT THE MAXEY FLATS RADIOACTIVE WASTE BURIAL SITE - 1974 TO 1975

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Radiation Programs

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This report discusses radiological measurements made by the Radiochemistry and Nuclear Engineering Branch, Cincinnati, at the request of the ORP Technology Assessment Division in support of EPA's program to obtain data on the principles and processes of land burial and the actual impact on the environment of presently operating commercial burial facilities.

The information obtained indicates that the quantities of radioactivity detected outside the burial trenches are so low that they do not appear to be a significant hazard to the environment or to public health in the Maxey Flats area, at the present time. However, the potential long-range impact of these contaminants is not known.

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# RADIOLOGICAL MEASUREMENTS AT THE MAXEY FLATS RADIOACTIVE WASTE BURIAL SITE - 1974 to 1975

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January 1977

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# FOREWORD

The Office of Radiation Programs (ORP) of the Environmental Protection Agency (EPA) carries out a national program designed to evaluate population exposure to ionizing and non-ionizing radiation and to prepare Federal radiation protection guidance and generally applicable environmental standards necessary to protect the environment and public health. In order to carry out these responsibilities, the EPA has performed field studies at nuclear facilities and sites. These field studies have required the development of means for identifying and quantifying any released radionuclides, as well as the methodology for evaluating facility discharge pathways and environmental transport.

Within the ORP, radioactive waste management has been assigned a high priority, and requires participation and cooperation with several State and Federal agencies. This report is one of a series directed at a specific EPA task to establish radiation protection guidelines and criteria for radioactive waste management and disposal, based on environmental pathways and radiation exposure levels. Other reports, recommendations and State assistance projects are being developed and executed to fulfill EPA obligations in the management and disposal of all types of radioactive wastes, including high-level wastes, low-level wastes, transuranium-contaminated wastes, uranium mill tailings, naturally-occurring radioactive wastes, and wastes from decommissioned nuclear facilities.

This report discusses radiological measurements made by the Radiochemistry and Nuclear Engineering Branch, Cincinnati, at the request of the ORP Technology Assessment Division in support of EPA's program to obtain data on the principles and processes of land burial and the actual impact on the environment of presently operating commercial burial facilities. These measurements also furnished technical support, which was requested by the State, and they were obtained in cooperation with the Kentucky Department for Human Resources (KDHR).

The information obtained indicates that the quantities of radioactivity detected outside the burial trenches are so low that they do not appear to be a significant hazard to the environment or to public health in the Maxey Flats area, at the present time. However, the potential long-range impact of these contaminants is not known.

This report supplements and expands upon reports previously published by the EPA and the KDHR. Observations presented in these earlier reports were used as the basis for this study. Particular attention was focused on the potential pathways from the burial site to man, and the radionuclide composition of the effluent discharged to the atmosphere from the evaporator system used in trench water control operations. It was not the intent of this study to ascertain the relative significance of suggested mechanisms by which radioactivity could migrate from the burial trenches. Hydrogeological studies being conducted by the U.S. Geological Survey concurrent with further radiological measurements may provide information on the latter, as well as furnish data useful in predicting the future impact of the burial site on the surrounding environment. Information obtained and surveillance methodologies developed at the Maxey Flats site will be utilized in planning and conducting similar studies under consideration at other commercial burial sites.

Review comments were received from the Nuclear Regulatory Commission, the Energy Research and Development Administration, the U.S. Geological Survey, several State laboratories, the Oak Ridge National Laboratory, the Kentucky Department for Human Resources, and the Nuclear Engineering Company, Inc.; and they were quite useful in the final editing of this report. Additional comments on this report would be appreciated. These should be sent to the Director, Technology Assessment Division (AW-459), Office of Radiation Programs, Environmental Protection Agency, 401 M Street, S.W., Washington, D. C. 20460.

W. D. Rowe, Ph.D.
Deputy Assistant Administrator
for Radiation Programs

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# 1. INTRODUCTION

## 1.1 Need for Study

The Maxey Flats radioactive waste burial site, operated by the Nuclear Engineering Company, Inc. (NECO), is presently the largest commercial depository in the United States. It contains approximately 40 percent of all commercially-generated low-level radioactive wastes buried in the U.S. Solid wastes containing low-level radioactivity are received at the site for burial from hospitals, research facilities, industrial radioisotope users, nuclear generating stations and related facilities.(1) Until 1972, liquid wastes solidified in a cement and paper mixture were also buried. Since 1972, however, the deposit of liquid wastes has been prohibited and only solid wastes are now accepted for burial.(2) The wastes are received in 210-liter (55-gal) steel drums as well as plastic, wood, and cardboard containers, which are buried in trenches 76 to 110 m long, 6 m wide and 6 m deep. When full, the trenches are capped with at least 1 m of compacted soil and, in recent years, fescue and clover have been planted in the trench area to retard erosion.

Burial operations at the Maxey Flats site began in May 1963.(3) During the past 13 years, approximately 121,000 $m^3$ of waste containing more than 1.92 million curies of radioactive material, 376 kg of special nuclear material and 154,000 kg of source material have been deposited.(4) The cumulative waste volume has increased nearly exponentially, from 2200 $m^3$ in the first year to about 70,000 $m^3$ in 1971 and 121,000 $m^3$ in 1975.(4,5) Most of the increase in the later years has been attributed to nuclear power plant operations.

A comprehensive inventory of radionuclides present in these waste materials will soon be available.(6) The wastes include relatively long-lived fission products, many activation products, and the actinides. Although concentrations of transuranium radionuclides are now limited to 10 nCi/g for deposit, it is estimated that 80 kg of $^{239}Pu$ plus additional quantities of other plutonium isotopes have been buried at the site.(3) Tritium is probably the most abundant radionuclide in the trenches ranging from less than 1 Ci to a maximum of 650,000 Ci in trench No. 31.(7)

In 1972, environmental monitoring by the Kentucky Department for Human Resources (KDHR) indicated that transport of radioactivity from the burial site was occurring. In 1974, small quantities of radioactivity were detected in test wells, surface water and soil on-site, and in surface water and soil at some nearby off-site locations.(8) The principal radionuclides reported by KDHR were $^{3}H$, $^{54}Mn$, $^{60}Co$, $^{90}Sr$, $^{137}Cs$, $^{238}Pu$ and $^{239}Pu$ in samples collected on-site, while in the off-site samples $^{3}H$, $^{90}Sr$, $^{238}Pu$ and $^{239}Pu$ were detected in soil and $^{3}H$ in surface water.

Investigations revealed that infiltrating rain water apparently leached radioactivity from the wastes, producing a radioactive leachate that could move through the adjacent subsurface soil and rocks. Contamination on the surface, due to evaporator plume depletion, container leakage during burial and possibly the trench-pumping operation, could also be carried off-site.(2) Four major routes for the transport of radioactivity to the surrounding environment have been proposed:(2,8,9)

1) surface water run-off,

2) lateral migration from the trenches through the soil zone,

3) migration from the trenches through fissure systems in the surrounding rocks, and

4) atmospheric fallout from the evaporator plume.

The extent of migration by routes 2 and 3 would be influenced by such factors as rainfall, depth to water table, the ion-exchange properties of the soil and rock, soil and rock permeability, surface gradient, and the distance the radioactive material must migrate before surfacing in a free-flowing water supply.(10)

During the past three years, NECO has conducted a program to reduce the movement of radioactivity from the burial site. Since it was assumed that trench water resulted from infiltration of precipitation rather than from groundwater, the permeability of the trench caps was reduced by adding additional soil with further compacting, and reshaping the caps to facilitate run-off.(2) Also, while filling the trenches, the wastes deposited are covered routinely by back filling with uncontaminated soil and any water that accumulates is pumped out.(11) The surface of the burial site has been regraded to improve surface drainage, cover has been planted to retard erosion, and, of immediate importance, the water was pumped from the trenches to large holding tanks. This leachate is evaporated to reduce the volume, and the residue from the evaporator is stored in a large tank. When approval is obtained from KDHR, this residue will be solidified and buried on site. The trenches are routinely examined for water and are pumped as often as additional water accumulates.(11) However, all trenches have not yet been pumped, e.g., #31, due to high $^{3}H$ levels.

At the present time, only small quantities of radioactivity have been detected in the environment surrounding the burial site, and so far these are believed to represent no health hazard.(2,8) However, the existence of radioactivity off-site requires special attention and a better understanding of the future environmental impact of the site.

The factors influencing migration of radioactivity listed above differ at the six commercial radioactive burial sites -- Maxey Flats, Kentucky; West Valley, New York; Barnwell, South Carolina; Sheffield, Illinois; Beatty, Nevada; and Richland, Washington.(12,13) There are, however, sufficient generic similarities among these sites which might allow data acquired at Maxey Flats to assist in evaluating the potential radiological impact of the others. For example, at the West Valley site the infiltration and accumulation of rain water in burial trenches have led to the movement of radioactivity off site.(13,14)

## 1.2 The Burial Site

The site occupies a 1.3-km$^2$ (330-acre) tract of land located on Maxey Flats, a flat-topped ridge in Fleming County, about 10 km NW of Morehead, Kentucky. The trenches and working areas are fenced, excluding access by the public to these areas. The surface of the ridge lies about 100 m above the surrounding valleys, and is relatively narrow, varying from about 150 m to 600 m wide. The region is drained by tributaries of the Licking River, which joins the Ohio River near Cincinnati, Ohio. The site drains to the east into No-Name Hollow Creek, to the west into Drip Springs Hollow Creek and to the south into Rock Lick Creek. Both No-Name Hollow Creek and Drip Springs Hollow Creek join Rock Lick Creek which flows west into Fox Creek and thence to the Licking River (see Figure 3.2). About 75 percent of the surface run-off flows east down a wash and into No-Name Hollow Creek.(9)

Rainfall in the region varies with season, being least in the fall and most abundant in spring and early summer. The average annual rainfall at Flemingsburg (about 22 km NW of the burial site) is 117 cm (46 in).(15) Rainfall in a 24-hour period during thunderstorms, common in spring and summer, frequently exceeds 7 cm and occasionally reaches 12 to 15 cm. Heavy rains commonly cause flooding in the valleys.

Parts of the upland areas and valleys are cleared for agricultural use; the hillsides are heavily forested. The major agricultural crops are tobacco, corn and forage for both beef and dairy cattle. In addition to family milk and beef cattle, three commercial dairy farms are known to exist within 4 km of the site, the closest being about 2 km SSW. Small family vegetable gardens are common. Game in the area includes deer, quail, grouse, raccoons, squirrels, rabbits, oppossums, etc. Fish occur in Crane Creek, north of the burial site, and Fox Creek. The water in Rock Lick Creek is insufficient to support fish throughout the year. Only a few minnows, crayfish and some benthic organisms were observed in Rock Lick Creek.

A survey of occupied homes, conducted on July 1, 1976, yielded 20 houses and 9 trailer homes within a 1.61 km radius of the burial site. Estimating 3.2 persons per dwelling, the population density is about 11 persons/km$^2$. There are a few scattered farm families on the east-west road along the ridge, and at present, five families live along Rock Lick Creek Road in the valley south of the burial site. The nearest population center (7,200) is Morehead, Kentucky, 10 km southeast of the site. During the school year, enrollment at Morehead State University may nearly double the town's population.

## 1.3 The Study

Investigations to date were performed in 10 field trips to the burial site and its environs between October 1974 and October 1975. The principal purposes of the trips were to:

1. Identify and measure radionuclides in the evaporator effluents discharged to the atmosphere, and attempt to determine decontamination factors of the evaporator system for the principal radionuclides.
2. Measure the radionuclide content of selected aquatic and terrestrial samples to identify potential pathways and, possibly, the critical pathways to man.
3. Measure radionuclides in selected environmental and test-well samples to support and supplement KDHR measurements.

The study was undertaken at the request of the Technology Assessment Division, ORP, USEPA, in support of EPA's program to obtain data on the principles and processes of land burial and the actual impact on the environment of presently operating commercial burial facilities. In addition, these studies furnished technical support which was requested by the State and were implemented in cooperation with the KDHR.

The study was performed by the Radiochemistry and Nuclear Engineering Branch, Cincinnati, with the support of the Technology Assessment Division, ORP, USEPA, and the Radiation and Product Safety Branch, KDHR. Assisting the investigators were individuals, listed in Appendix 9, from the KDHR, the U.S. Geological Survey, the U.S. Environmental Protection Agency, and the Nuclear Engineering Company.

## 2. EVAPORATOR STUDY

### 2.1 Introduction

The Nuclear Engineering Company (NECO) instituted in 1972 a water removal program to alleviate waste management problems caused by rain water infiltrating and saturating filled radioactive waste trenches. Water contaminated by waste radionuclides was suspected to be migrating from the storage trenches to springs, streams and domestic wells located in adjacent valleys beyond the restricted area of the site.(8) The trenches were estimated at the time to contain as much as $4 \times 10^6$ liters ($10^6$ gallons) of liquid.(16)

NECO began in 1972 to pump leachate from the trenches to 48 large steel storage tanks with a total capacity of $2.5 \times 10^6$ liters ($6.7 \times 10^5$ gal).(3,7) The tanks were mounted horizontally above ground on wooden ties in an area surrounded by a berm, or dike, to contain potential leakage. The site operator installed an evaporator plant in 1973 and started treatment of wastes accumulated in the tanks on a 40-hours-per-week basis in July 1973. During the latter half of 1974, the feed material consisted mostly of water that had accumulated in the berm area from precipitation and which had become contaminated by tank leakage. Since January 1975, evaporation of stored waste was being conducted 24 hours per day, five days per week.

The evaporator plant, described in Section 2.3, concentrates non-volatile radionuclides in the wastes by boiling off the liquid fraction. At Maxey Flats, however, this fraction contains relatively high concentrations of tritium plus other radionuclides not completely removed by the process. The degree of liquid decontamination depends on radionuclide volatility, with volatile species such as iodine and ruthenium being less susceptible to decontamination than nonvolatile ones. Other factors affecting evaporator decontamination include pH of the waste feed, presence of organic matter, and design of the evaporator itself, particularly as to the degree to which liquid droplets containing particulate radionuclides can be entrained by effluent vapor and discharged.(17)

Rain water collected in the diked area is used for dilution when relatively high-level radioactive trench water is to be evaporated, to assure that ambient concentrations of effluents off-site remain below permissible values. During this study, this water was contaminated by waste leaking from tanks. NECO began in mid-1975 to transfer this water to an adjacent diked area ("lined pond") that included a double-layer; impermeable liner on the sides and bottom and another over the top of the water. During the latter part of 1975 the number of storage tanks was being reduced to approximately ten. The pumping of the trenches was being continued except for some containing very high amounts of $^{3}H$.(7)

The evaporator effluent containing water vapor and particles is discharged directly to the atmosphere and dispersed by wind. The airborne water vapor fraction, containing tritium, is removed primarily by precipitation when moving over land and the airborne particles settle out or fall with precipitation. Atmospheric half-residence values cited recently are 28 days for water vapor removed by rain and 30 days for particles.(18)

## 2.2 Radionuclides in Storage Tanks

KDHR sampled the contents of 44 storage tanks in October 1973 for analysis by the EPA Eastern Environmental Radiation Facility (EERF).(19) Radionuclide concentrations in the various tanks varied widely, as expected. Tritium, $^{60}Co$, $^{90}Sr$ and $^{137}Cs$ were present in the liquid of all tanks. Other measured radionuclides included $^{54}Mn$, $^{65}Zn$, $^{106}Ru$, $^{125}Sb$, $^{134}Cs$, $^{228}Ac$ ($^{228}Ra$), $^{238}Pu$, $^{239}Pu$ and $^{240}Pu$. The samples were not analyzed by EERF for concentrations of $^{14}C$, $^{55}Fe$, $^{129}I$, $^{226}Ra$ and other long-lived actinides (U, $^{241}Am$, etc.).

The maximum and average concentrations of the more radiologically significant radionuclides in stored trench water are given below. Their significance was determined by a comparison of their volume-weighted average concentrations, computed from the EERF results, with their permissible concentrations in environmental air.

| | Concentration, µCi/ml | |
|---|---|---|
| | maximum | average |
| $^{3}H$ | $2.7 \times 10^{1}$ | 2.1 |
| $^{60}Co$ | $9.6 \times 10^{-4}$ | $2.3 \times 10^{-4}$ |
| $^{90}Sr$ | $4.8 \times 10^{-3}$ | $4.7 \times 10^{-4}$ |
| $^{137}Cs$ | $4.2 \times 10^{-3}$ | $4.3 \times 10^{-4}$ |
| $^{238}Pu$ | $1.5 \times 10^{-3}$ | $9.5 \times 10^{-5}$ |
| $^{239}Pu$ | $7.4 \times 10^{-5}$ | $4.5 \times 10^{-6}$ |

## 2.3 Description of the Evaporator System(11,17,20)

The evaporator plant consists essentially of two 3800-liter (1000-gal) settling tanks, filter units, evaporator, and discharge system, all of which are housed in the evaporator building. Their primary purposes are to pre-treat waste to remove solid material, evaporate the liquid, and discharge the vapor to the atmosphere. A schematic of the evaporator system is shown in Figure 2.1.

Waste liquid is drained from the storage tanks through valves located about 15 cm above the tank bottom and pumped through hoses to one of the settling tanks, which are filled to the 3000-liter (800-gal) level. When dilution is necessary, water from the lined pond (formerly, from the tank berm area) is added at the settling tank. Up to the end of June 1975, the tanks were filled alternately and the contents held for 1.5 hours to allow solids to settle by gravity. As a result of initial measurements by this laboratory, the site operator started in early 1975 to test various chemical additives to enhance settling. After June 1975, the operator instituted plant modifications which included pumping the waste into the first settling tank, adding a lime flocculating agent, and stirring the contents with air for a few minutes. After settling for 1 hr, the clarified liquid is withdrawn from the upper part of the tank and pumped to the second tank through a 75-μm cartridge filter. Liquid collected in this tank is fed continuously through another 75-μm filter and a 5-μm filter to the evaporator.

The evaporator, a submerged-combustion type manufactured by the Ozark-Mahoning Co., is fueled by a mixture of propane gas and air. The burner is immersed in the liquid which is heated by combustion gases bubbling through it. A silicone-based antifoam agent is added at the evaporator to reduce radionuclide entrainment in vapor caused by bubbles, which result primarily from heating organic material.

The liquid feed rate to the evaporator is nominally 17 liters/min (4.5 gal/min), for which a combustion heat rate of $7.9 \times 10^{12}$ ergs/s ($2.7 \times 10^6$ BTU/hr) is required. The temperature of the vapor leaving the evaporator is 89°C (193°F). Its volumetric flow rate is 860 liters/s (30.3 $ft^3/s$). Gases formed by evaporating trench water and burning propane consist of:(21)

| Gas | Volume, % |
|---|---|
| water vapor (from evaporation) | 57.3 |
| water vapor (from combustion) | 6.4 |
| $N_2$ | 31.2 |
| $O_2$ | 0.40 |
| $CO_2$ | 4.7 |

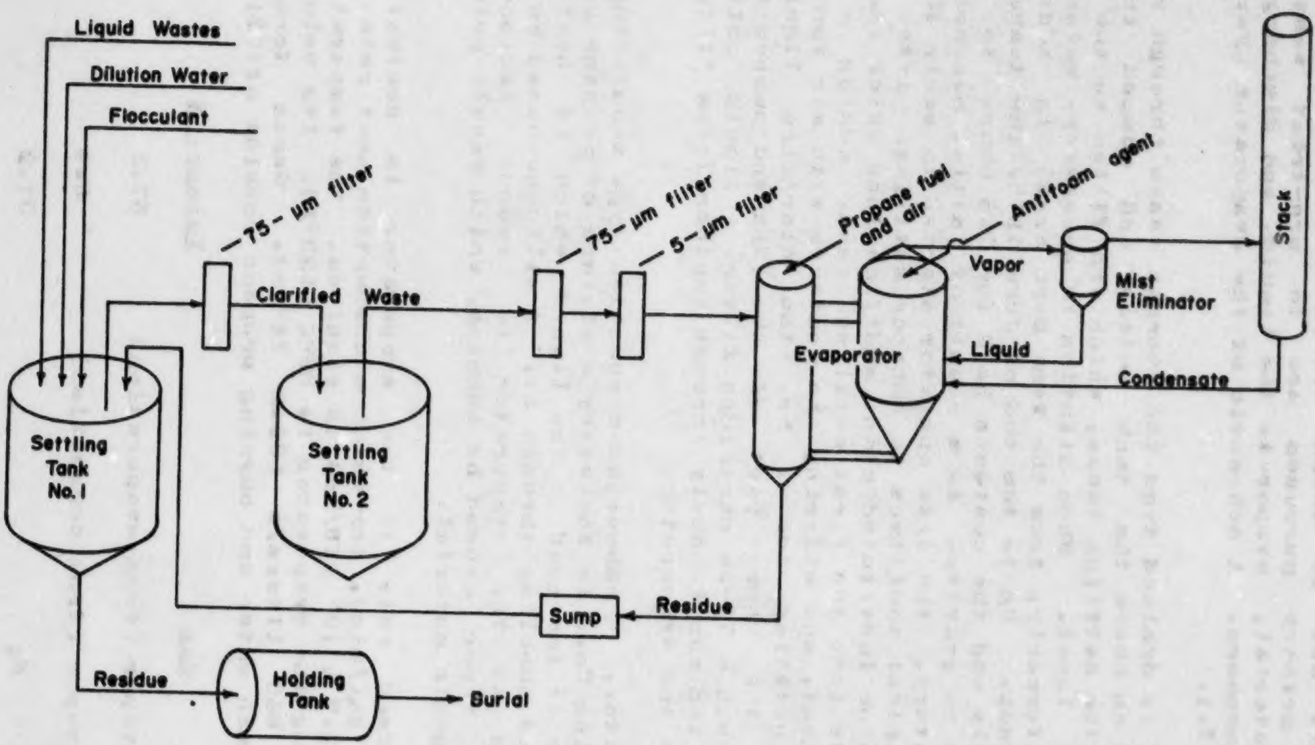

Figure 2.1 Evaporator Treatment Process (As of October 1, 1975)

Water vapor produced by propane combustion dilutes the waste liquid by approximately 10 percent.

The evaporator exhaust flows through a centrifugal separator type of mist eliminator to remove entrained water droplets. The effluent is discharged to the atmosphere through a 30-cm-diameter steel pipe that passes horizontally through the side of the building and rises outside to a height of 10 m (33 ft) above ground level.

The slurry-like sediment at the bottom of settling tank no. 1 is removed daily (formerly weekly from both tanks when they were operated alternately) and pumped to one of five holding tanks for eventual solidification and burial. Residue collected in the evaporator is discharged every 30 min to the first settling tank. Liquid from the mist eliminator returns to the evaporator as does the small amount of condensate formed in the stack. Spent filters are buried on-site.

Early tests conducted by NECO indicated the decontamination factor (radionuclide concentrations of input divided by output) of the evaporator alone to be 40 or greater, based on gross alpha- and beta-particle (excluding tritium) and gamma-ray measurements. Tritium, which is affected very little by the treatment system, was identified as the most significant effluent radionuclide relative to permissible airborne concentration levels in areas beyond the site fenceline.(21)

Samples of evaporator effluent are composited and analyzed daily for $^3$H and gross alpha- and beta-particle and gamma-ray radioactivity. Wind speed and direction instruments are mounted 2 m above the building, and their readings are recorded continuously inside. According to a program established by NECO, wind data and tank $^3$H concentration values provide at the beginning of each 8-hr shift the basis for determining whether and how much dilution water is required to assure that ambient $^3$H concentrations remain below the permissible levels established by KDHR, which conform to 10CFR20 recommendations.(22)

## 2.4 Sample Collection

2.4.1 General. Evaporator stack effluents were measured on four occasions, during each of which four or five tests were conducted. Table 2.1 presents test dates, sampling intervals and actual sampling durations, and identifications and fractions of storage tank liquid being processed (the remainder consisted of dilution water from the berm and lined pond areas). The amounts of air and water sampled from the stack discharge are also listed.

The first trip (tests nos. 1 to 5) provided an operational check of the stack sampling system. At the time, contaminated water from the berm area was being evaporated. During the second

Table 2.1

Evaporator Stack Effluent Sampling Data

| Test no. | Date | Period, hrs | Sampling duration, min | Evaporator feed (amount, %) | Sample volumes | |
|---|---|---|---|---|---|---|
| | | | | | air, $m^3$ | water, liters |
| 1 | Nov. 6, 1974 | 1320-1447 | 62 | berm (100) | 1.30 | 1.37 |
| 2 | Nov. 6, 1974 | 1605-1705 | 55 | berm (100) | 1.15 | 1.26 |
| 3 | Nov. 7, 1974 | 0928-1235 | 172 | berm (100) | 3.53 | 3.78 |
| 4 | Nov. 7, 1974 | 1429-1654 | 128 | berm (100) | 2.62 | 2.63 |
| 5 | Nov. 8, 1974 | 0923-1123 | 111 | berm (100) | 2.33 | 2.53 |
| 6 | Apr. 8, 1975 | 1343-1547 | 102 | tank 5 (50) | 2.14 | 2.55 |
| 7 | Apr. 9, 1975 | 0955-1123 | 88 | tank 5 (50) | 1.85 | 2.17 |
| 8 | Apr. 9, 1975 | 1343-1622 | 155 | tank 10 (35) | 3.26 | 3.70 |
| 9 | Apr. 10, 1975 | 1000-1150 | 104 | tank 10 (100) | 1.26 | 2.30 |
| 10 | May 20, 1975 | 1606-1635 | 20 | tank 46 (100) | 0.42 | 0.51 |
| 11 | May 21, 1975 | 0934-1130 | 112 | tank 46 (100) | 2.35 | 2.25 |
| 12 | May 21, 1975 | 1331-1535 | 120 | tank 46 (100) | 2.52 | 2.52 |
| 13 | May 22, 1975 | 0948-1125 | 92 | tank 36 (100) | 1.93 | 1.77 |
| 14 | Sept. 29, 1975 | 1333-1540 | 120 | tank 9 (50) | 2.52 | 2.54 |
| 15 | Sept. 30, 1975 | 0926-1059 | 90 | tank 9 (50) | 1.89 | 1.72 |
| 16 | Sept. 30, 1975 | 1303-1503 | 116 | tank 9 (50) | 2.44 | 2.34 |
| 17 | Oct. 1, 1975 | 1018-1145 | 81 | tank 5A (50) | 1.76 | 1.65 |

test series (nos. 6 to 9), waste liquids were generally being processed with dilution water, because light winds prevailed. Since effluent radionuclide concentrations differed significantly during apparently identical evaporation conditions (tests 6 and 7), another series (nos. 10 to 13) was performed. Its purpose was to measure emissions while the contents of one tank (no. 46) were being treated with constant operating conditions. This tank reportedly contained many radionuclides and a volume sufficient for 2.5 days of operation. The study was hampered, however, by plant shutdowns, omission of the antifoam agent in test no. 11, and the emptying of tank no. 46 after test no. 12. Tests nos. 14 to 17 were conducted to measure effluents during the lime flocculation treatment.

2.4.2 Stack effluent sampler. Since no stack sampling probe was installed at the time, a sampler for this study was devised for mounting on the top flange of the stack. Effluents were withdrawn through a nylon nozzle with an inside diameter of 0.64 cm (0.25 in), inserted downward into the stack about 18 cm (7 in) and about 10 cm (3.8 in) from the interior wall. The sampled air was pumped continuously to ground level through a 0.8-cm (0.31 in) inside-diameter rubber hose to the sample collectors, depicted in Figure 2.2. Water vapor was removed from incoming air by condensation in a 3-liter glass flask immersed in an ice-water bath, followed by two small backup flasks in ice water. Particles in the then essentially dried air were removed by a 5.4-cm (2.1-in) glass fiber filter (Mine Safety Appliances Co. type 1106) mounted in a leak-tight holder. Air flow rate was determined with a pre-calibrated Gelman type 8223 flow meter. Constant flow was maintained by a regulator on the vacuum pump. Adjustments were necessary only when the filter became loaded with small particles. During some tests, changes of air filters were required because they were clogged by an abundance of fine particles, and these were composited for analyses. Some samples were given to NECO personnel for crosscheck measurements.

The evaporator effluent enters the stack at 1180 cm/s (38.6 ft/s) when the volumetric flow rate is 860 liters/s and its temperature is 362°K (193°F).(21) Stack effluent temperature measured at its discharge point during November 1974 ranged between 325°K (125°F) and 333°K (140°F). This temperature drop reduces the volumetric flow rate at the stack exit approximately 9 percent. The modified flow rate divided by the ratio of the inside cross-sectional areas of the stack and sample nozzle (2300:1) yields a result of 20.4 liters/min, the flow rate needed for isokinetic sampling.

2.4.3 In-plant sample collection. During each stack discharge measurement, samples of waste being treated were collected in 125- or 250-ml plastic bottles from the settling tanks and the evaporator. Sampling data are provided in Appendix 2. Obtaining representative samples was difficult due to the nature of the settling and evaporation processes and the varying

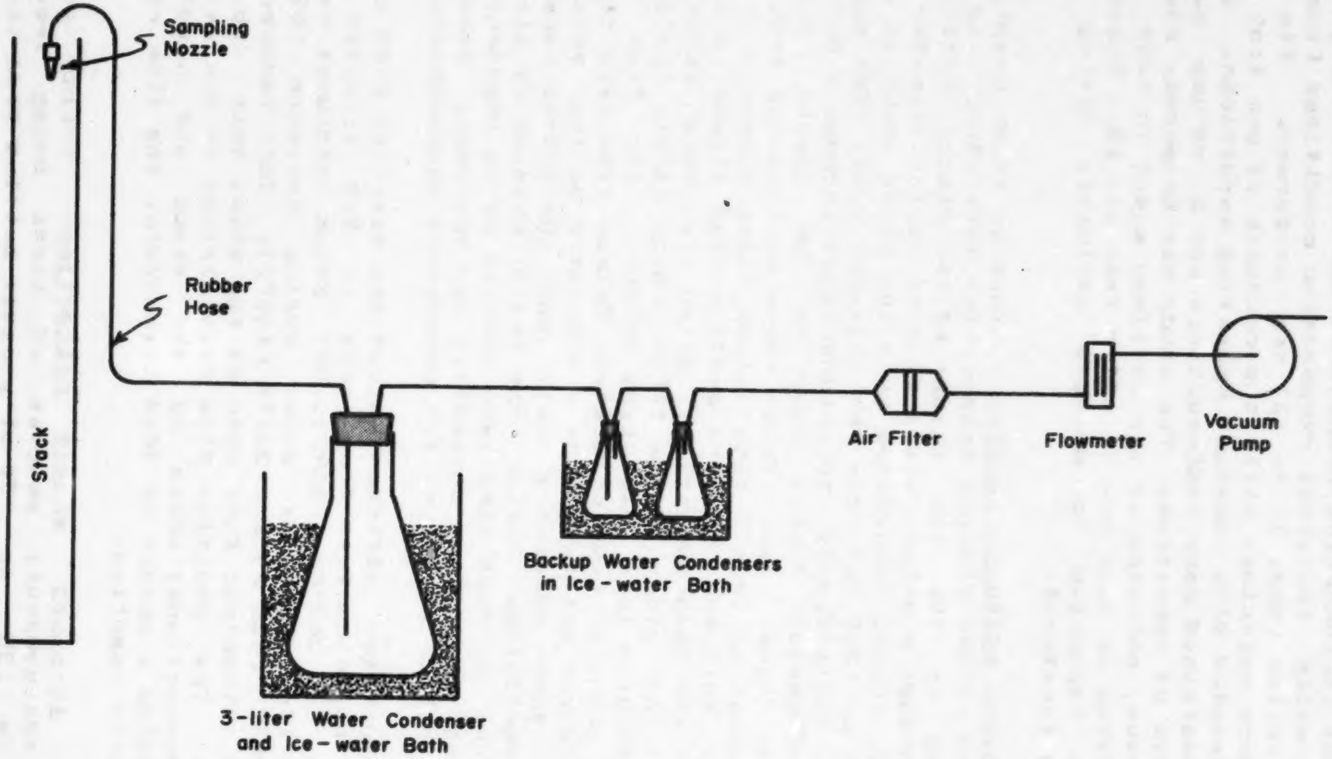
Sampling Nozzle
Rubber Hose
Stack
3-liter Water Condenser and Ice-water Bath
Backup Water Condensers in Ice-water Bath
Air Filter
Flowmeter
Vacuum Pump

Figure 2.2 Collection Train for Sampling Evaporator Stack Effluent

composition of the waste. Samples of settling tank contents were dipped from the top. Evaporator contents were obtained during the first trip from a drain valve located between the two vessels. A new evaporator core was installed after this trip, and thereafter samples were collected usually from a valve on the liquid level gauge.

Two sets of samples were obtained during the flocculation treatment being used in settling tank no. 1 at the time of the fourth trip. One sample was collected at the top of the tank after the contents were stirred with air and the second, after the flocculant was added and the contents settled for approximately 30 min.

A one-liter liquid sample from the top of the tank no. 5A was obtained on September 29, 1975, and 4 liters from the bottom, on September 25, 1975. One-liter liquid samples of the top and bottom of tank no. 9 were taken on September 29, 1975.

Samples of water used to dilute liquid waste were obtained as the water was being added to the settling tank. Six 125-ml aliquots of water from the berm water catchment area were collected from November 6 to 8, 1974. A 4-liter sample of water from the lined pond was obtained on October 1, 1975.

### 2.5 Radionuclide Analysis

2.5.1 General. Water collected during each stack test was composited in a plastic bottle and the air filter was sealed in a plastic bag. Upon return to the laboratory, each water sample was weighed and passed usually through a 0.8-μm membrane filter to remove suspended solids (0.45-μm filters were difficult to use due to very rapid clogging). The filter was dried, weighed and mounted on a stainless steel planchet.

All test containers and samples bore a yellow oily substance that apparently accompanies stack discharge. No radioactivity, however, was found to be associated with it. Presence of the oily substance on the air filters prevented gross alpha-particle measurements. The plastic water bottles and rubber hose for stack sampling were also analyzed by gamma-ray spectrometry after use and no radioactivity was found to have adhered to internal surfaces.

Radionuclides in solids collected on the air filter, in the filtered condensed water and in material collected on the 0.8 μm membrane filter were measured by gamma-ray spectrometry or radiochemical techniques. Radionuclide concentrations that were not measurable were below the minimum detectable concentration limits given in Appendix 1. These values were calculated at the 99.7 percent (3 σ) confidence level using typical sample volumes and instrument counting intervals.

Samples collected within the evaporator plant were filtered after return to the laboratory. Membrane filters of 0.45-μm pore size were used, occasionally along with a glass fiber pre-filter when excessive amounts of solids were present. All filtered water and suspended solids fractions were analyzed by gamma-ray spectroscopy using Ge(Li) detectors. For this, the water fractions were brought up to standard counting volumes of 200 or 400 ml with distilled water. Selected samples were analyzed also for $^{3}H$ and $^{90}Sr$ contents. In general, the analytical sensitivity levels given in Appendix 1 apply for in-plant samples.

2.5.2 Gamma-ray spectrometry. Radionuclides that emit gamma rays of 40 to 2048 keV were analyzed with 55- or 85-cm$^3$ Ge(Li) detectors coupled to 2048-channel pulse-height analyzers. Air and membrane filters were placed on the detector face for counting; the filtered water was placed in a plastic container for this measurement. Ge(Li) detection efficiencies for the various sample geometries and volumes were determined by calibrations with mixed gamma-ray point source and solution radioactivity standards prepared by the National Bureau of Standards.

2.5.3 Radiochemical analysis. Tritium was measured using duplicate 1-ml aliquots of the filtered water, diluted to 100 ml and distilled. One ml of the distillate was mixed with 19 ml of Instagel scintillation solution and counted in a liquid scintillation counter for three 100-min periods.

Strontium was chemically separated from one half of each of the membrane or glass fiber filters and from 200- to 500-ml aliquots of filtered water. The radiostrontium content was measured by counting for 100-min intervals with low background Geiger-Mueller beta-particle detectors. Strontium-90 was distinguished from $^{89}Sr$ by separating and counting the $^{90}Y$ daughter (see Appendix 7).

The gross alpha-particle activity of the membrane filters or 100 ml of filtered water dried on a stainless steel planchet was measured with internal proportional counters for an interval of 900 min.

Plutonium was also chemically separated from one half of the filters and 200 ml of filtered water after the addition of a known amount of $^{242}Pu$ to determine chemical yield. The plutonium was electrodeposited on stainless steel planchets and analyzed for 4000 min by alpha spectrometry, using a 400-mm$^2$ silicon surface barrier detector (see Appendix 7).

Carbon-14 in the filtered water sample fraction was oxidized to $CO_2$, converted to $CaCO_3$ precipitate, and mounted on a stainless steel planchet for measurement with a low-background beta counter. Iron-55 was chemically separated and measured with a xenon-filled x-ray proportional counter and a multichannel pulse-height analyzer.

## 2.6 Results and Discussion of Evaporator Measurements

2.6.1 *Radionuclide concentrations in stack effluent from the evaporation of berm water*. Radionuclide concentrations in the air filter and water sample fractions during processing of berm water are listed in Tables 2.2 and 2.3, respectively. No radioactivity was detected by gamma-ray spectrometry in the suspended solids fraction. However, since Whatman type 41 filter paper was used in this case, radioactivity may have been associated with small particle size material (<4 µm). The discharge contained $^{3}$H, $^{54}$Mn, $^{60}$Co, $^{90}$Sr, $^{134}$Cs and $^{137}$Cs. Tritium was the most abundant radionuclide, at an average concentration of $7.6 \times 10^{-2}$ µCi/ml.

These results represent concentrations in water from the berm area as of early November 1974. Concentrations of radionuclides at any given time could be affected by many factors. These include occurrences of storage tank leakage, rainfall, evaporation, sedimentation, fallout from nuclear weapons testing and scavenging of effluents from the evaporator stack plume as it passes over the area.

2.6.2 *Radionuclide concentrations in stack effluent from the evaporation of storage tank liquids*. Fifteen long-lived radionuclides were identified in stack effluent during evaporation of wastes from six different tanks. Radionuclide concentrations were measured in the air filters and the suspended and dissolved material fractions of the water samples. Sample measurements for tests nos. 6 to 9 are given in Table 2.4, tests nos. 10 to 13 in Table 2.5 and tests nos. 14 to 17 in Table 2.6.

Tritium, observed in every sample of stack discharge, was the predominant radionuclide, ranging in concentration up to 1.79 µCi/ml of water. Also observed in every test were $^{60}$Co, $^{90}$Sr and $^{137}$Cs. Sodium-22, $^{106}$Ru and $^{134}$Cs were detected frequently and $^{54}$Mn, $^{125}$Sb, $^{226}$Ra and $^{228}$Ac (progeny of 5.75-yr $^{228}$Ra), occasionally. Strontium-89 was not measurable in any test. Carbon-14 was found in the three filtered water samples (tests nos. 6, 10, and 12) chosen for analysis, and may be present in other sample fractions as well as other test samples, since it is reported to be present in most trenches.(5) Iron-55 was measured in one of two samples analyzed. Plutonium-238 and $^{239}$Pu were found in the three sample sets analyzed. Iodine-131 was observed in stack discharge during two consecutive tests. NECO reported that waste containing $^{131}$I was processed about 10 days earlier.(11) Apparently $^{131}$I was retained on surfaces within the plant and was being removed slowly. Although observed in samples from within the plant (see Appendix 3), $^{65}$Zn and $^{241}$Am were not measurable in stack effluents by gamma-ray spectrometry.

Table 2.2

Radionuclide Concentrations in Air Samples of Evaporator Stack Effluent during Berm Water Evaporation, Tests 1-5, μCi/ml of Air

| Radionuclide | Test no.* | | |
|---|---|---|---|
| | 1 | 2 | 3 & 4 |
| $^{54}$Mn | ND | ND | $2 \pm 1 \times 10^{-13}$ |
| $^{60}$Co | ND | $1.5 \pm 0.7 \times 10^{-12}$ | $2 \pm 1 \times 10^{-13}$ |
| $^{90}$Sr | $3.1 \pm 0.3 \times 10^{-12}$ | $4.7 \pm 0.3 \times 10^{-12}$ | $1.9 \pm 0.1 \times 10^{-12}$ |
| $^{134}$Cs | ND | ND | $3 \pm 1 \times 10^{-13}$ |
| $^{137}$Cs | $5.7 \pm 0.8 \times 10^{-12}$ | $1.0 \pm 0.1 \times 10^{-11}$ | $4.6 \pm 0.3 \times 10^{-12}$ |

*Air sample for Test 5 given to NECO for analyses.

Notes:

1. ± values indicate analytical error at 2-sigma confidence level of the count rate.
2. ND - not detectable (see Appendix 1).

Table 2.3

Radionuclide Concentrations in Water Samples of Evaporator Stack Effluent during Berm Water Evaporation, Tests 1-5, μCi/ml of Water

| nuclide | Test no. | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| $^{3}H$ | 7.3 ± 0.1 x $10^{-2}$ | 7.6 ± 0.1 x $10^{-2}$ | 7.8 ± 0.1 x $10^{-2}$ | 7.6 ± 0.1 x $10^{-2}$ | 7.8 ± 0.1 x $10^{-2}$ |
| $^{90}Sr$ | 1.3 ± 0.1 x $10^{-7}$ | 1.3 ± 0.1 x $10^{-7}$ | 1.7 ± 0.1 x $10^{-7}$ | 1.5 ± 0.1 x $10^{-7}$ | 1.4 ± 0.1 x $10^{-7}$ |
| $^{137}Cs$ | 5 ± 1 x $10^{-8}$ | 4 ± 1 x $10^{-8}$ | 5 ± 1 x $10^{-8}$ | 5.0 ± 0.8 x $10^{-8}$ | 4.4 ± 0.9 x $10^{-8}$ |

Note: ± values indicate analytical error at 2-sigma confidence level.

## Table 2.4

Radionuclide Concentrations in Air and Water Samples of Evaporator Stack Effluent, Tests 6-9, µCi/ml of Air or Water

| Radionuclide | Sample type* | Test no. | | | |
|---|---|---|---|---|---|
| | | 6 | 7 | 8 | 9 |
| $^{3}H$ | W | $4.4 \pm 0.1 \times 10^{-1}$ | $1.47 \pm 0.06 \times 10^{-1}$ | $3.05 \pm 0.08 \times 10^{-1}$ | $1.79 \pm 0.02$ |
| $^{14}C$ | A | NA | NA | NA | NA |
| | W | $5 \pm 3 \times 10^{-8}$ | NA | NA | NA |
| | F | NA | NA | NA | NA |
| $^{22}Na$ | A | $9 \pm 5 \times 10^{-13}$ | ND | ND | ND |
| | W | ND | ND | ND | ND |
| | F | ND | ND | ND | ND |
| $^{55}Fe$ | A | ND | NA | NA | NA |
| | W | NA | NA | NA | NA |
| | F | NA | NA | NA | NA |
| $^{60}Co$ | A | $4.1 \pm 0.2 \times 10^{-11}$ | $1.8 \pm 0.1 \times 10^{-11}$ | $5.6 \pm 0.1 \times 10^{-11}$ | $2.90 \pm 0.05 \times 10^{-10}$ |
| | W | $1.3 \pm 0.2 \times 10^{-7}$ | $1.0 \pm 0.2 \times 10^{-7}$ | $3 \pm 1 \times 10^{-8}$ | $3.5 \pm 0.2 \times 10^{-7}$ |
| | F | $5 \pm 1 \times 10^{-9}$ | $2.1 \pm 0.7 \times 10^{-9}$ | $1.7 \pm 0.5 \times 10^{-9}$ | $1.80 \pm 0.04 \times 10^{-7}$ |
| $^{90}Sr$ | A | $8.4 \pm 0.9 \times 10^{-13}$ | $4.7 \pm 0.1 \times 10^{-13}$ | $2.0 \pm 0.1 \times 10^{-12}$ | $1.80 \pm 0.02 \times 10^{-10}$ |
| | W | $2.4 \pm 0.2 \times 10^{-8}$ | $1.5 \pm 0.1 \times 10^{-8}$ | $1.3 \pm 0.03 \times 10^{-7}$ | $1.90 \pm 0.05 \times 10^{-6}$ |
| | F | $1.5 \pm 0.8 \times 10^{-10}$ | ND | $4 \pm 1 \times 10^{-10}$ | $3.5 \pm 0.2 \times 10^{-9}$ |
| $^{106}Ru$ | A | $1.8 \pm 0.4 \times 10^{-11}$ | ND | ND | ND |
| | W | ND | ND | ND | ND |
| | F | $9 \pm 7 \times 10^{-9}$ | ND | ND | ND |
| $^{125}Sb$ | A | $5.8 \pm 0.1 \times 10^{-12}$ | $2 \pm 1 \times 10^{-12}$ | ND | ND |
| | W | ND | ND | ND | ND |
| | F | ND | ND | ND | ND |
| $^{131}I$ | A | $1.2 \pm 0.1 \times 10^{-11}$ | $1.3 \pm 0.6 \times 10^{-12}$ | ND | ND |
| | W | $2.8 \pm 0.8 \times 10^{-8}$ | ND | ND | ND |
| | F | ND | ND | ND | ND |
| $^{134}Cs$ | A | $1.1 \pm 0.6 \times 10^{-12}$ | ND | ND | $1.7 \pm 0.2 \times 10^{-11}$ |
| | W | ND | ND | ND | $4 \pm 1 \times 10^{-8}$ |
| | F | ND | ND | ND | ND |
| $^{137}Cs$ | A | $1.7 \pm 0.1 \times 10^{-11}$ | $7.2 \pm 0.8 \times 10^{-12}$ | $8.9 \pm 0.1 \times 10^{-11}$ | $4.6 \pm 0.1 \times 10^{-10}$ |
| | W | $3 \pm 1 \times 10^{-8}$ | $1.2 \pm 0.9 \times 10^{-8}$ | $3 \pm 1 \times 10^{-8}$ | $1.2 \pm 0.3 \times 10^{-6}$ |
| | F | ND | ND | ND | $2 \pm 1 \times 10^{-9}$ |
| $^{226}Ra$ | A | ND | ND | ND | ND |
| | W | ND | $1.5 \pm 0.9 \times 10^{-7}$ | ND | ND |
| | F | ND | ND | $4 \pm 3 \times 10^{-9}$ | ND |
| $^{228}Ac$ | A | $3 \pm 2 \times 10^{-12}$ | ND | $1.2 \pm 0.8 \times 10^{-12}$ | ND |
| | W | ND | ND | ND | ND |
| | F | ND | ND | ND | ND |
| $^{238}Pu$ | A | NA | $5.5 \pm 0.4 \times 10^{-13}$ | NA | $1.4 \pm 0.5 \times 10^{-13}$ |
| | W | NA | ND | NA | $4.1 \pm 0.8 \times 10^{-10}$ |
| | F | NA | $2.0 \pm 0.1 \times 10^{-9}$ | NA | $1.8 \pm 0.2 \times 10^{-9}$ |
| $^{239}Pu$ | A | NA | ND | NA | ND |
| | W | NA | ND | NA | ND |
| | F | NA | $8 \pm 3 \times 10^{-11}$ | NA | $5 \pm 3 \times 10^{-11}$ |
| Gross α | A | NA | NA | NA | NA |
| | W | $3.5 \pm 0.1 \times 10^{-8}$ | $1.5 \pm 0.1 \times 10^{-8}$ | $3.9 \pm 0.7 \times 10^{-9}$ | $2.7 \pm 0.1 \times 10^{-8}$ |
| | F | $1.30 \pm 0.01 \times 10^{-8}$ | $1.80 \pm 0.02 \times 10^{-8}$ | $9.0 \pm 0.2 \times 10^{-9}$ | $2.50 \pm 0.02 \times 10^{-8}$ |

*Sample types: A - air filter; W - water passed through a 0.8-µm filter; F - 0.8-µm membrane filter through which water sample was passed.

Notes:

1. ± values indicate analytical error at 2-sigma confidence level.
2. ND - not detectable (see Appendix 1).
3. NA - not analyzed.

Table 2.5

Radionuclide Concentrations in Air and Water Samples of Evaporator Stack Effluent, Tests 10-13, µCi/ml of Air or Water

| Radio-nuclide | Sample type* | Test no. 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|
| $^{3}$H | W | $6.19 \pm 0.01 \times 10^{-1}$ | $1.09 \pm 0.01$ | $1.01 \pm 0.01$ | $2.70 \pm 0.01 \times 10^{-1}$ |
| $^{14}$C | A | NA | NA | NA | NA |
|  | W | $1.8 \pm 0.3 \times 10^{-7}$ | NA | $2.4 \pm 0.1 \times 10^{-6}$ | NA |
|  | F | NA | NA | NA | NA |
| $^{22}$Na | A | $1.6 \pm 0.2 \times 10^{-11}$ | $2.6 \pm 0.9 \times 10^{-12}$ | $3.5 \pm 0.8 \times 10^{-12}$ | $2.1 \pm 0.9 \times 10^{-12}$ |
|  | W | $4 \pm 1 \times 10^{-8}$ | $2.2 \pm 0.3 \times 10^{-7}$ | $6 \pm 2 \times 10^{-8}$ | $7 \pm 2 \times 10^{-8}$ |
|  | F | ND | ND | ND | ND |
| $^{54}$Mn | A | $3 \pm 2 \times 10^{-12}$ | ND | ND | ND |
|  | W | ND | ND | ND | ND |
|  | F | $2 \pm 1 \times 10^{-8}$ | $5 \pm 4 \times 10^{-9}$ | ND | ND |
| $^{55}$Fe | A | ND | NA | NA | NA |
|  | W | ND | NA | NA | NA |
|  | F | $6 \pm 3 \times 10^{-8}$ | NA | NA | NA |
| $^{60}$Co | A | $2.10 \pm 0.04 \times 10^{-11}$ | $1.20 \pm 0.03 \times 10^{-10}$ | $1.00 \pm 0.03 \times 10^{-10}$ | $6.8 \pm 0.2 \times 10^{-11}$ |
|  | W | $4.9 \pm 0.4 \times 10^{-7}$ | $2.5 \pm 0.1 \times 10^{-6}$ | $1.20 \pm 0.06 \times 10^{-6}$ | $1.10 \pm 0.05 \times 10^{-6}$ |
|  | F | $3.4 \pm 0.1 \times 10^{-7}$ | $7.7 \pm 0.1 \times 10^{-7}$ | $7.0 \pm 0.1 \times 10^{-8}$ | $2.5 \pm 0.2 \times 10^{-8}$ |
| $^{90}$Sr | A | $3.4 \pm 0.1 \times 10^{-11}$ | $4.3 \pm 0.1 \times 10^{-11}$ | $3.1 \pm 0.1 \times 10^{-11}$ | $1.9 \pm 0.3 \times 10^{-11}$ |
|  | W | $2.00 \pm 0.01 \times 10^{-6}$ | $9.6 \pm 0.2 \times 10^{-7}$ | $5.8 \pm 0.1 \times 10^{-7}$ | $5.2 \pm 0.1 \times 10^{-7}$ |
|  | F | $1.1 \pm 0.1 \times 10^{-8}$ | $6.1 \pm 0.2 \times 10^{-8}$ | $1.10 \pm 0.06 \times 10^{-8}$ | $4.5 \pm 0.2 \times 10^{-9}$ |
| $^{106}$Ru | A | $1.3 \pm 0.2 \times 10^{-11}$ | $7.6 \pm 0.9 \times 10^{-11}$ | $5 \pm 1 \times 10^{-11}$ | $4 \pm 1 \times 10^{-11}$ |
|  | W | ND | ND | ND | ND |
|  | F | $2.9 \pm 0.4 \times 10^{-7}$ | $1.30 \pm 0.05 \times 10^{-6}$ | $1.50 \pm 0.05 \times 10^{-7}$ | $1.0 \pm 0.1 \times 10^{-7}$ |
| $^{134}$Cs | A | $3.10 \pm 0.04 \times 10^{-11}$ | $4.8 \pm 0.2 \times 10^{-11}$ | $4.4 \pm 0.2 \times 10^{-11}$ | $2.6 \pm 0.2 \times 10^{-11}$ |
|  | W | $8.5 \pm 0.4 \times 10^{-7}$ | $2.8 \pm 0.1 \times 10^{-6}$ | $1.00 \pm 0.05 \times 10^{-6}$ | $1.00 \pm 0.05 \times 10^{-6}$ |
|  | F | ND | ND | ND | ND |
| $^{137}$Cs | A | $2.60 \pm 0.02 \times 10^{-9}$ | $5.60 \pm 0.04 \times 10^{-10}$ | $5.20 \pm 0.04 \times 10^{-10}$ | $3.60 \pm 0.04 \times 10^{-10}$ |
|  | W | $6.0 \pm 0.1 \times 10^{-6}$ | $2.60 \pm 0.02 \times 10^{-5}$ | $1.00 \pm 0.01 \times 10^{-5}$ | $1.20 \pm 0.01 \times 10^{-5}$ |
|  | F | $1.9 \pm 0.4 \times 10^{-8}$ | $3.10 \pm 0.04 \times 10^{-8}$ | $3.4 \pm 0.4 \times 10^{-9}$ | $3.9 \pm 0.9 \times 10^{-9}$ |
| $^{226}$Ra | A | ND | ND | ND | ND |
|  | W | ND | ND | ND | $5.6 \pm 0.3 \times 10^{-7}$ |
|  | F | ND | ND | ND | $5 \pm 1 \times 10^{-8}$ |
| Gross α | A | --- | --- | --- | --- |
|  | W | $6.7 \pm 0.3 \times 10^{-7}$ | $2.70 \pm 0.06 \times 10^{-6}$ | $1.50 \pm 0.05 \times 10^{-6}$ | $5.2 \pm 0.2 \times 10^{-7}$ |
|  | F | $1.00 \pm 0.02 \times 10^{-6}$ | $3.50 \pm 0.06 \times 10^{-7}$ | $3.6 \pm 0.1 \times 10^{-7}$ | $8.5 \pm 0.4 \times 10^{-8}$ |

*Samples types: A - air filter; W - water passed through a 0.8-µm filter; F - 0.8-µm membrane filter through which water sample was passed.

Notes:

1. ± values indicate analytical error at 2-sigma confidence level.
2. ND - not detectable (see Appendix 1).
3. NA - not analyzed.

## Table 2.6

### Radionuclide Concentrations in Evaporator Stack Effluent, Tests 14-17, μCi/ml of Air or Water

| Radio-nuclide | Sample type* | Test no. 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|
| $^{3}H$ | W | $1.73 \pm 0.01$ | $1.64 \pm 0.02$ | $2.42 \pm 0.01$ | $9.71 \pm 0.01 \times 10^{-1}$ |
| $^{22}Na$ | A | ND | ND | ND | $4 \pm 2 \times 10^{-12}$ |
| | W | $2 \pm 1 \times 10^{-8}$ | $2 \pm 1 \times 10^{-8}$ | $4 \pm 2 \times 10^{-8}$ | $6 \pm 1 \times 10^{-8}$ |
| | F | ND | ND | ND | ND |
| $^{60}Co$ | A | $2.6 \pm 0.3 \times 10^{-11}$ | $4.5 \pm 0.2 \times 10^{-11}$ | $5.8 \pm 0.4 \times 10^{-11}$ | $1.20 \pm 0.06 \times 10^{-10}$ |
| | W | $4.3 \pm 0.3 \times 10^{-7}$ | $8.5 \pm 0.4 \times 10^{-7}$ | $1.20 \pm 0.04 \times 10^{-6}$ | $1.20 \pm 0.04 \times 10^{-6}$ |
| | F | $3.7 \pm 0.2 \times 10^{-8}$ | $3.3 \pm 0.2 \times 10^{-8}$ | $5.7 \pm 0.5 \times 10^{-8}$ | $3.8 \pm 0.2 \times 10^{-8}$ |
| $^{90}Sr$ | A | $4.5 \pm 0.4 \times 10^{-12}$ | $5.4 \pm 0.9 \times 10^{-12}$ | $6.1 \pm 0.6 \times 10^{-12}$ | $1.3 \pm 0.1 \times 10^{-11}$ |
| | W | $2.7 \pm 0.1 \times 10^{-7}$ | $2.7 \pm 0.1 \times 10^{-7}$ | $3.3 \pm 0.1 \times 10^{-7}$ | $3.6 \pm 0.1 \times 10^{-7}$ |
| | F | $4.6 \pm 0.7 \times 10^{-9}$ | $2.3 \pm 0.3 \times 10^{-9}$ | ND | ND |
| $^{106}Ru$ | A | ND | ND | ND | $5 \pm 3 \times 10^{-11}$ |
| | W | ND | ND | ND | ND |
| | F | $3.4 \pm 0.9 \times 10^{-8}$ | $5.1 \pm 0.9 \times 10^{-8}$ | $7.4 \pm 0.2 \times 10^{-8}$ | $1.5 \pm 0.1 \times 10^{-7}$ |
| $^{125}Sb$ | A | ND | ND | $9 \pm 2 \times 10^{-12}$ | $3 \pm 1 \times 10^{-11}$ |
| | W | ND | ND | ND | ND |
| | F | ND | ND | $1.4 \pm 0.6 \times 10^{-8}$ | $1.1 \pm 0.3 \times 10^{-8}$ |
| $^{134}Cs$ | A | $1.6 \pm 0.1 \times 10^{-10}$ | $1.00 \pm 0.03 \times 10^{-10}$ | $1.1 \pm 0.2 \times 10^{-10}$ | $2.4 \pm 0.1 \times 10^{-10}$ |
| | W | $3.1 \pm 0.1 \times 10^{-6}$ | $2.9 \pm 0.1 \times 10^{-6}$ | $3.5 \pm 0.1 \times 10^{-6}$ | $2.5 \pm 0.1 \times 10^{-6}$ |
| | F | $3 \pm 1 \times 10^{-9}$ | ND | $6 \pm 3 \times 10^{-9}$ | $2 \pm 1 \times 10^{-9}$ |
| $^{137}Cs$ | A | $1.3 \pm 0.1 \times 10^{-9}$ | $7.7 \pm 0.1 \times 10^{-10}$ | $7.9 \pm 0.1 \times 10^{-10}$ | $2.10 \pm 0.02 \times 10^{-9}$ |
| | W | $2.30 \pm 0.01 \times 10^{-5}$ | $2.20 \pm 0.02 \times 10^{-5}$ | $2.6 \pm 0.2 \times 10^{-5}$ | $1.9 \pm 0.1 \times 10^{-5}$ |
| | F | $2.4 \pm 0.2 \times 10^{-8}$ | $1.2 \pm 0.1 \times 10^{-8}$ | $3.5 \pm 0.3 \times 10^{-8}$ | $1.2 \pm 0.1 \times 10^{-8}$ |
| $^{238}Pu$ | A | NA | NA | $4.6 \pm 0.6 \times 10^{-12}$ | NA |
| | W | NA | NA | $2.4 \pm 0.2 \times 10^{-9}$ | NA |
| | F | NA | NA | $1.0 \pm 0.1 \times 10^{-8}$ | NA |
| $^{239}Pu$ | A | NA | NA | $6 \pm 2 \times 10^{-13}$ | NA |
| | W | NA | NA | ND | NA |
| | F | NA | NA | ND | NA |
| Gross α | A | NA | NA | NA | NA |
| | W | $1.00 \pm 0.02 \times 10^{-7}$ | $5.5 \pm 0.3 \times 10^{-8}$ | $1.10 \pm 0.02 \times 10^{-7}$ | $1.10 \pm 0.02 \times 10^{-7}$ |
| | F | $2.4 \pm 0.1 \times 10^{-8}$ | $1.00 \pm 0.05 \times 10^{-8}$ | $1.4 \pm 0.1 \times 10^{-8}$ | $1.60 \pm 0.02 \times 10^{-8}$ |

*Sample types: A - air filter; W - water passed through a 0.8-μm filter; F - 0.8-μm membrane filter through which water sample was passed.

Notes:

1. ± values indicate analytical error at 2-sigma confidence level.
2. ND - not detectable (see Appendix 1).
3. NA - not analyzed.

Water collected from stack discharge was usually slightly basic. The pH ranged between 7.2 and 7.6, except that in tests nos. 8 and 9 the values were 6.9 and 5.6, respectively.

Comparison of the amount of each radionuclide found in the filtered water fraction to the total quantity in the sample set indicated its solubility in stack discharge. The index was computed by $c_W v_W/q$, where $c_W$ denotes the radionuclide concentration in filtered water; $v_W$, the volume of water collected, and $q$, the total quantity of the radionuclide. The latter term represents the sum of the products of $c$ and $v$ for all three sample fractions: filtered water, material collected on the membrane filter, and the air filter.

Based on sample sets in which the radionuclide was measured with satisfactory precision, over 90 percent of $^{22}$Na, $^{90}$Sr, $^{134}$Cs, $^{137}$Cs and $^{226}$Ra was not filterable. The same was true of most $^{60}$Co (>70 percent). Ruthenium-106 was completely insoluble, and $^{54}$Mn, $^{55}$Fe, $^{125}$Sb, $^{228}$Ac and Pu were associated mostly with undissolved material. The solubility of $^{14}$C is uncertain at this time.

2.6.3 *Radionuclide discharge rates from evaporator stack.* Total emission rates to the atmosphere of radionuclides measured in the 17 tests are listed in Table 2.7. The rates were calculated from sample concentration values as follows:

$$Q_i = 2300\, q_i/t,$$

where

$Q_i$ = discharge rate of radionuclide i, µCi/s

2300 = ratio of internal cross-sectional areas of stack to sampling nozzle (see Sections 2.3 and 2.4.2)

$q_i$ = quantity of radionuclide i measured in all sample fractions (see Section 2.6.2), µCi

$t$ = sampling time (see Table 2.1), s

Discharge rates during processing of water from the berm area (tests nos. 1 to 5) were averaged for Table 2.7, since the values were relatively constant. The tritium discharge rate was about 65 µCi/s ± 5 percent. Strontium-90 rates varied within ± 10 percent and $^{137}$Cs, ± 4 percent.

Emission rates of the various radionuclides determined from test no. 6 measurements exceeded those during test no. 7 by several fold, although during both tests, waste from tank no. 5 was reportedly being treated with equal volumes of dilution water. Of particular interest, $^{3}$H releases during the former test were three-fold higher, indicating possibly that the actual

Table 2.7

Summary of Radionuclide Discharge Rates (Q) from Evaporator Stack, μCi/sec

| Radionuclide | Test no. |  |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | 1-5 (avg.) | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| $^{3}\mathrm{H}$ | 6.5(1) | 4.2(2) | 1.4(2) | 2.8(2) | 1.5(3) | 6.0(2) | 8.4(2) | 8.2(2) | 2.0(2) | 1.4(3) | 1.2(3) | 1.9(3) | 7.6(2) |
| $^{14}\mathrm{C}$ | NA | 4.7(-5) | NA | NA | NA | 1.8(-4) | NA | 1.9(-3) | NA | NA | NA | NA | NA |
| $^{22}\mathrm{Na}$ | ND | 6.8(-7) | ND | ND | ND | 5.5(-5) | 1.7(-4) | 5.1(-5) | 5.5(-5) | 1.4(-5) | 1.4(-5) | 3.2(-5) | 5.2(-5) |
| $^{54}\mathrm{Mn}$ | ND | ND | ND | ND | ND | 1.8(-5) | 3.7(-6) | ND | ND | ND | ND | ND | ND |
| $^{55}\mathrm{Fe}$ | NA | ND | NA | NA | NA | 5.3(-5) | NA | NA | NA | NA | NA | NA | NA |
| $^{60}\mathrm{Co}$ | 6.8(-7) | 1.6(-4) | 3.3(-5) | 3.1(-5) | 6.8(-4) | 1.0(-3) | 2.6(-3) | 1.1(-3) | 8.9(-4) | 4.0(-4) | 6.9(-4) | 1.0(-3) | 1.1(-3) |
| $^{90}\mathrm{Sr}$ | 1.2(-4) | 2.5(-5) | 1.5(-5) | 1.2(-4) | 1.7(-3) | 2.3(-4) | 8.2(-4) | 5.0(-4) | 4.1(-4) | 2.2(-4) | 2.0(-4) | 2.6(-4) | 2.9(-4) |
| $^{106}\mathrm{Ru}$ | ND | 2.5(-5) | ND | ND | ND | 3.9(-4) | 1.1(-3) | 1.6(-4) | 1.1(-4) | 2.7(-5) | 3.7(-5) | 5.8(-5) | 1.5(-4) |
| $^{125}\mathrm{Sb}$ | ND | 4.4(-6) | 1.4(-6) | ND | ND | ND | ND | ND | ND | ND | ND | 1.8(-5) | 3.0(-5) |
| $^{131}\mathrm{I}$ | ND | 3.7(-5) | 1.2(-6) | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| $^{134}\mathrm{Cs}$ | ND | 8.7(-7) | ND | ND | 4.7(-5) | 1.1(-3) | 2.2(-3) | 8.4(-4) | 7.7(-4) | 2.6(-3) | 2.2(-3) | 2.8(-3) | 2.1(-3) |
| $^{137}\mathrm{Cs}$ | 4.3(-5) | 4.4(-5) | 7.8(-6) | 4.1(-5) | 1.4(-3) | 8.0(-3) | 2.1(-2) | 8.6(-3) | 8.9(-3) | 2.0(-2) | 1.7(-2) | 2.1(-2) | 1.6(-2) |
| $^{226}\mathrm{Ra}$ | ND | ND | 8.4(-5) | 3.6(-6) | ND | ND | ND | ND | 4.5(-4) | ND | ND | ND | ND |
| $^{228}\mathrm{Ac}$ | ND | 2.1(-6) | ND | 7.7(-7) | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| $^{238}\mathrm{Pu}$ | NA | NA | 2.3(-6) | NA | 1.9(-6) | NA | NA | NA | NA | NA | NA | 1.4(-5) | NA |
| $^{239}\mathrm{Pu}$ | NA | NA | 7.0(-8) | NA | 4.4(-8) | NA | NA | NA | NA | NA | NA | 4.6(-7) | NA |
| Gross α | NA | 4.6(-5) | 3.1(-5) | 1.2(-5) | 4.3(-5) | 1.6(-3) | 2.3(-3) | 1.5(-3) | 4.3(-4) | 1.0(-4) | 4.8(-5) | 9.3(-5) | 9.9(-5) |

Notes:

1. ND - not detectable; NA - not analyzed.
2. ( ) indicates exponent of 10, e.g., (-2) = x $10^{-2}$.

dilution was significantly different. Waste from another tank (no. 4), processed about 8 hrs before test no. 6, was considered as a cause, but $^3$H concentrations in both tanks were similar.(19)

Similar differences were noted in discharges during tests nos. 8 and 9, even after normalizing the data to account for the dilution water added during test no. 8 (2 parts dilution to 1 part waste). Tritium discharge was five-fold higher in test no. 9 rather than the anticipated three-fold. Discharge rates of other radionuclides were 14 to 33 times higher.

Discharge rates during tests nos. 10 to 12 were expected to be similar and were in these cases, except for $^3$H. This radionuclide was about 25 percent lower than the two succeeding tests. This may have reflected $^3$H levels in wastes treated before tank no. 46 (processing of tank no. 4 ended just before test no. 10 was initiated). Release rates of radionuclides other than $^3$H during test no. 11 were generally three-fold higher than during tests nos. 10 and 12. It was learned later that defoaming agent was not being added during this test, which may have been the cause.

During tests nos. 14 to 16, waste was being processed with equal volumes of dilution water. Discharge rates of all radionuclides during the first two tests, however, were only 40 to 80 percent of those determined in test no. 16. Tritium notably was about 30 percent lower in the first two runs.

It is evident from the results of these tests that the contents of radionuclides other than $^3$H in stack effluent are significantly influenced by treatment of previous storage tank liquids for a period longer than expected. That is, radionuclides from previous batches appear to be re-introduced to the evaporator input from some point in the system, probably the residue in the settling tanks including that from the evaporator, which makes it difficult to compare accurately evaporator effluent concentrations with storage tank concentrations.

2.6.4 Radionuclide concentrations in liquids processed during tests. Concentrations of radionuclides in waste contained in storage tanks nos. 5, 10, 36 and 46 are given in Table 2.8. These are results of samples obtained by KDHR on October 18, 1973, and analyzed by the EPA Eastern Environmental Radiation Facility in early 1974.(19)

Radionuclide contents in tanks 5A (denotes tank no. 5 after refilling) and 9 are listed in Table 2.9 according to the radionuclide concentrations associated with dissolved material and suspended solids in samples from the top and bottom portions of the storage tanks. Concentrations in these two tanks tend to be similar in the two portions, with most radioactivity being

## Table 2.8

## Radionuclide Concentrations in Four Liquid Waste Tanks,* Processed During Tests Nos. 6 to 13, µCi/ml

| Radionuclide | Tank no. | | | |
|---|---|---|---|---|
| | 5 | 10 | 36 | 46 |
| $^{3}$H | 1.6 ± 0.05 | 2.3 ± 0.01 | 4.9 ± 0.01(-1) | 1.3 ± 0.01 |
| $^{54}$Mn | 1.3 ± 0.2(-5) | ND | ND | 2.9 ± 0.2(-5) |
| $^{60}$Co | 5.9 ± 0.1(-4) | 1.3 ± 0.04(-4) | 2.2 ± 0.04(-4) | 3.8 ± 0.04(-4) |
| $^{90}$Sr | 1.2 ± 0.1(-4) | 5.3 ± 0.1(-4) | 8.9 ± 0.4(-4) | 1.5 ± 0.06(-4) |
| $^{106}$Ru | 1,8 ± 0.1(-4) | 1.9 ± 0.4(-5) | ND | 3.2 ± 0.6(-5) |
| $^{134}$Cs | 6.3 ± 0.1(-4) | 1.5 ± 0.1(-5) | ND | 9 ± 1(-6) |
| $^{137}$Cs | 4.2 ± 0.01(-3) | 1.6 ± 0.03(-4) | 2.1 ± 0.1 (-5) | 1.3 ± 0.02(-4) |
| $^{228}$Ac | ND | 6.8 ± 0.5(-5) | ND | ND |
| $^{238}$Pu | 1.0 ± 0.1(-4) | 1.5 ± 0.1(-3) | 1.9 ± 0.2(-7) | 3.2 ± 0.3(-5) |
| $^{239}$Pu | 5.7 ± 0.6(-6) | 7.4 ± 0.7(-5) | 5 ± 1(-8) | 9 ± 1(-7) |

* Measurements by EPA Eastern Environmental Radiation Facility for KDHR.(19) Samples obtained Oct. 18, 1973, and analyzed for $^{3}$H and $^{90}$Sr during Jan. to Mar. 1974 and for gamma-ray emitters, Mar. and Apr. 1974. Disintegration rates apply at time of analyses.

Notes:

1. ( ) indicates exponent of 10, e.g., (-2) = x $10^{-2}$.
2. ND - not detectable.

Table 2.9

Radionuclide Concentrations in Liquid Waste Tanks Nos. 5A and 9

Processed During Tests Nos. 14 to 17, µCi/ml

|  | Dissolved material |  | Suspended solids |  |
|---|---|---|---|---|
|  | tank top | tank bottom | tank top | tank bottom |
|  |  | Tank No. 5A |  |  |
| $^{3}H$ | $1.46 \pm 0.01$ | $1.46 \times 0.01$ | --- | --- |
| $^{22}Na$ | $3.6 \pm 0.8 \times 10^{-7}$ | $3 \pm 2 \times 10^{-7}$ | ND | ND |
| $^{60}Co$ | $1.20 \pm 0.01 \times 10^{-4}$ | $1.20 \pm 0.01 \times 10^{-4}$ | $2.8 \pm 0.1 \times 10^{-6}$ | $1.3 \pm 0.1 \times 10^{-6}$ |
| $^{90}Sr$ | $1.20 \pm 0.01 \times 10^{-4}$ | $1.10 \pm 0.01 \times 10^{-4}$ | $2.80 \pm 0.04 \times 10^{-6}$ | $1.20 \pm 0.03 \times 10^{-6}$ |
| $^{106}Ru$ | $1.6 \pm 0.1 \times 10^{-5}$ | $1.7 \pm 0.1 \times 10^{-5}$ | $5 \pm 2 \times 10^{-7}$ | $4 \pm 1 \times 10^{-7}$ |
| $^{125}Sb$ | $1.2 \pm 0.3 \times 10^{-6}$ | $4.3 \pm 0.4 \times 10^{-6}$ | ND | ND |
| $^{137}Cs$ | $1.2 \pm 0.1 \times 10^{-6}$ | $2.3 \pm 0.2 \times 10^{-6}$ | $1.3 \pm 0.3 \times 10^{-7}$ | $4.4 \pm 0.2 \times 10^{-8}$ |
| Gross alpha | $2.0 \pm 0.1 \times 10^{-4}$ | $2.0 \pm 0.1 \times 10^{-4}$ | $1.00 \pm 0.04 \times 10^{-5}$ | $1.70 \pm 0.05 \times 10^{-5}$ |
|  |  | Tank No. 9 |  |  |
| $^{3}H$ | $5.84 \pm 0.01$ | $5.79 \pm 0.01$ | --- | --- |
| $^{22}Na$ | $3 \pm 1 \times 10^{-7}$ | $4 \pm 1 \times 10^{-7}$ | ND | ND |
| $^{60}Co$ | $4.0 \pm 0.1 \times 10^{-5}$ | $3.9 \pm 0.1 \times 10^{-5}$ | $8.3 \pm 0.2 \times 10^{-6}$ | $4.6 \pm 0.1 \times 10^{-6}$ |
| $^{90}Sr$ | $1.00 \pm 0.01 \times 10^{-4}$ | $9.80 \pm 0.01 \times 10^{-5}$ | $4.0 \pm 0.1 \times 10^{-6}$ | $1.00 \pm 0.01 \times 10^{-5}$ |
| $^{106}Ru$ | $1.4 \pm 0.2 \times 10^{-5}$ | $1.1 \pm 0.1 \times 10^{-5}$ | $1.0 \pm 0.3 \times 10^{-6}$ | $8 \pm 3 \times 10^{-7}$ |
| $^{125}Sb$ | $6 \pm 4 \times 10^{-7}$ | $5 \pm 3 \times 10^{-7}$ | $4.1 \pm 0.9 \times 10^{-7}$ | $2.6 \pm 0.8 \times 10^{-7}$ |
| $^{134}Cs$ | ND | ND | $1.3 \pm 0.6 \times 10^{-7}$ | ND |
| $^{137}Cs$ | $9 \pm 2 \times 10^{-7}$ | $1.5 \pm 0.2 \times 10^{-6}$ | $1.1 \pm 0.1 \times 10^{-6}$ | $6.3 \pm 0.6 \times 10^{-7}$ |
| $^{238}Pu$ | $1.1 \pm 0.1 \times 10^{-5}$ | NA | $1.4 \pm 0.1 \times 10^{-5}$ | NA |
| $^{239}Pu$ | ND | NA | $9 \pm 3 \times 10^{-8}$ | NA |
| Gross alpha | $1.9 \pm 0.1 \times 10^{-5}$ | $2.3 \pm 0.1 \times 10^{-5}$ | $1.9 \pm 0.1 \times 10^{-5}$ | $4.3 \pm 0.1 \times 10^{-4}$ |

Notes:
1. Dissolved material is that which passed through a 0.8-µm membrane filter; suspended solids collected on filter.
2. ± values indicate analytical precision expressed at the 95 percent confidence level.
3. ND - not detectable (see Appendix 1).

dissolved. The pH of the liquids in tanks nos. 5A and 9 were 8.8 and 8.0, respectively.

Concentrations in water used for dilution are given in Table 2.10. Dilution water contained $^{3}H$, $^{60}Co$, $^{90}Sr$, $^{106}Ru$, $^{134}Cs$ and $^{137}Cs$. These results apply at the time of sampling since concentration levels are affected by many factors, as discussed in Section 2.6.1.

2.6.5 __In-plant concentrations of tritium and other radionuclides__. Tritium concentrations in samples from the settling tanks and evaporator during the stack effluent measurements are given in Table 2.11. Although $^{3}H$ concentrations are not affected by the various pre-treatments in the evaporator building, they are reduced approximately 10 percent by dilution with water formed by propane combustion. This is demonstrated by comparing the similar $^{3}H$ levels in the settling tank and incoming water (see Table 2.10) during tests nos. 1 to 5 with those in stack effluent (see Table 2.3). In this case, the stack emission concentrations are 12 percent lower on the average.

Tritium levels in the evaporator are generally slightly lower than those in the settling tanks. In some cases, the much lower concentrations may have been due to incomplete draining of the evaporator sampling line or residue from waste batches previously processed.

Comparing $^{3}H$ concentrations measured in the storage tanks (see Tables 2.8 and 2.9) and in the stack effluent during tests nos. 6 to 17 (see Tables 2.4, 2.5 and 2.6) provides verification of the mixture of liquid waste and dilution water reported by the site operator. The reported and apparent (measured) fractions of liquid waste being treated are as follows:

| | Liquid waste fraction, percent | |
|---|---|---|
| Test no. | reported | apparent* |
| 6 | 50 | 35 |
| 7 | 50 | 10 |
| 8 | 35 | 10 |
| 9 | 100 | 90 |
| 10 | 100 | 55 |
| 11 | 100 | 85 |
| 12 | 100 | 90 |
| 13 | 100 | 65 |
| 14 | 50 | 35 |
| 15 | 50 | 30 |
| 16 | 50 | 45 |
| 17 | 50 | 75 |

*Based on concentrations measured in storage tank liquids and in-plant samples.

Table 2.10

Radionuclide Concentrations in Dilution Water, μCi/ml

| Radionuclide | Concentration |  |
|---|---|---|
|  | dissolved material | suspended solids |
|  | Nov. 6-8, 1974 |  |
| $^{3}H$ | $8.7 \pm 0.1 \times 10^{-2}$[*] | --- |
| $^{60}Co$ | $1.9 \pm 0.5 \times 10^{-7}$ | $5 \pm 4 \times 10^{-8}$ |
| $^{90}Sr$ | $2 \pm 1 \times 10^{-5}$ | $2 \pm 1 \times 10^{-7}$ |
| $^{137}Cs$ | $1.0 \pm 0.6 \times 10^{-7}$ | ND |
|  | Oct. 1, 1975 |  |
| $^{3}H$ | $2.31 \pm 0.01 \times 10^{-2}$[**] | --- |
| $^{60}Co$ | $2.3 \pm 0.2 \times 10^{-7}$ | $4.0 \pm 0.6 \times 10^{-8}$ |
| $^{90}Sr$ | $5.20 \pm 0.05 \times 10^{-6}$ | $7.7 \pm 0.4 \times 10^{-8}$ |
| $^{106}Ru$ | $9 \pm 8 \times 10^{-8}$ | ND |
| $^{134}Cs$ | ND | $4.1 \pm 0.6 \times 10^{-8}$ |
| $^{137}Cs$ | $7 \pm 1 \times 10^{-8}$ | $1.4 \pm 0.1 \times 10^{-7}$ |

---

[*] ± values represent dispersion at one standard deviation of analytical results of 6 samples.

[**] ± values indicate analytical precision at the 95 percent confidence level.

Table 2.11

Tritium Concentrations in Evaporator Plant during Tests, μCi/ml

| | Location | |
|---|---|---|
| Test no. | settling tank | evaporator |
| 1 | $8.3 \times 10^{-2}$ | $8.3 \times 10^{-2}$ |
| 2 | $8.8 \times 10^{-2}$ | $8.1 \times 10^{-2}$ |
| 3 | $8.7 \times 10^{-2}$ | $7.6 \times 10^{-2}$ |
| 4 | $8.7 \times 10^{-2}$ | $8.2 \times 10^{-2}$ |
| | $8.6 \times 10^{-2}$ | $8.0 \times 10^{-2}$ |
| 5 | $8.8 \times 10^{-2}$ | $8.0 \times 10^{-2}$ |
| 6 | $4.79 \times 10^{-1}$ | NA |
| 7 | NA | $1.62 \times 10^{-1}$ |
| 8 | NA | $2.52 \times 10^{-1}$ |
| 9 | NA | 2.11 |
| 10 | $7.74 \times 10^{-1}$ | $6.31 \times 10^{-1}$ |
| 11 | NA | $8.25 \times 10^{-1}$ |
| 12 | NA | $9.83 \times 10^{-1}$ |
| 13 | NA | $2.54 \times 10^{-1}$ |
| | NA | $2.71 \times 10^{-1}$ |
| 14 | 2.00 | NA |
| 15 | 2.68 | 1.59 |
| 16 | 2.80 | 2.24 |
| 17 | $9.70 \times 10^{-1}$ | $9.59 \times 10^{-1}$ |

Notes:

1. Analytical error of individual results is < ± 1 percent at the 95 percent confidence level.
2. NA - not analyzed.

Close agreement is noted for many tests while some, however, are widely different. Causes of the latter may be addition of waste with different $^{3}H$ concentration to the storage tank since the original analysis, effects of previous waste present in the settling tank bottoms, operator error, since the incoming waste liquid and dilution water are not always metered during mixing, or errors in sampling.

The concentration of other radionuclides measured in in-plant liquid are listed in Appendix 3. A list of all in-plant samples obtained during the tests is given in Appendix 2. Measured radionuclides included $^{22}Na$, $^{54}Mn$, $^{60}Co$, $^{65}Zn$, $^{90}Sr$, $^{106}Ru$, $^{125}Sb$, $^{134}Cs$, $^{137}Cs$, $^{226}Ra$, $^{228}Ac$ and $^{241}Am$. Only selected samples were analyzed for $^{90}Sr$. No analyses for $^{14}C$, $^{55}Fe$, $^{238}Pu$ or $^{239}Pu$ were performed.

2.6.6 Decontamination factors of the evaporator. Decontamination factors (DF) provide a measure of the effectiveness of the entire treatment system for removing various radionuclides from the waste liquid. Such factors, in turn, could be useful in estimating stack discharge rates resulting from processing a waste batch of known radionuclide composition.

Plant DF's were calculated for each radionuclide by dividing its concentration in incoming water (see Section 2.6.4) by that measured in stack discharge. The latter was determined by dividing the value of q for each test (see Section 2.6.2) by the amount of water collected in the stack sample (Table 2.1).

DF's derived for 7 principal radionuclides from six sample sets, each set representing waste from different storage tanks, are given in Table 2.12. The tests selected were those in which no plant malfunctions occurred, sample fractions were analyzed with good precision, and effluent $^{3}H$ concentrations approximated expected levels. The factors vary considerably, reflecting undoubtedly the chemical diversity of the waste and the complexity of the treatment process. Cesium DF's ranged over four magnitudes. The <1 values for tests nos. 16 and 17 arose from higher $^{137}Cs$ concentrations in stack effluent than in feed, which could have resulted from residual cesium of previous batches being removed from the plant. The DF's for Pu also showed large variations.

The DF's obtained in these six tests on an individual radionuclide basis confirm that the DF value of 40 derived from measurements by the site operator for the evaporator alone is reasonable and provides a conservative estimate of removal efficiency for the entire system.

## 2.7 Estimated Annual Radiation Dose Rates from Evaporator Stack Effluent

Table 2.12

**Decontamination Factors of Waste Processing System**

| | Test no. | | | | | |
|---|---|---|---|---|---|---|
| **Radionuclide** | **6** | **9** | **12** | **13** | **16** | **17** |
| $^{60}$Co | 1,040 | 140 | 230 | 100 | 17 | 67 |
| $^{90}$Sr | 1,460 | 250 | 240 | 1,050 | 170 | 320 |
| $^{106}$Ru | 1,160 | --- | 70 | --- | 81 | 85 |
| $^{134}$Cs | --- | 180 | 6 | --- | --- | --- |
| $^{137}$Cs | 30,000 | 96 | 11 | 1.1 | 0.04 | 0.07 |
| $^{238}$Pu* | --- | $6.4 \times 10^5$ | --- | --- | 700 | --- |
| $^{239}$Pu | --- | $1.4 \times 10^6$ | --- | --- | --- | --- |

*Also, a DF of 4300 for $^{238}$Pu was obtained with test no. 7 measurements.

Dose rates were estimated for the limiting receptor* to place in perspective the environmental impact of radionuclides discharged from the evaporator. The total annual dose was calculated on the bases of the average concentration of six principal radionuclides measured in the storage tanks in October 1973 (see Section 2.2) and the evaporator plant operating continuously throughout the year at a waste feed rate of 17 liters/min (4.5 gal/min). The decontamination factors applied for the various radionuclides were based on the average of the values given in Section 2.6.6, except for $^{137}$Cs. For the latter, a factor of 40 was used due to the large variation in measured values. Because of the larger analytical uncertainty associated with the $^{239}$Pu measurements, the DF for plutonium was based on the $^{238}$Pu data.

The residence of the limiting receptor, at which the maximum annual average air concentration occurs, was concluded to be the home at the entrance to the burial site. The residence is situated approximately 0.8 km distant from the evaporator stack at an azimuth of 21° (NNE) and at the same ground elevation (325 m) as the evaporator (see Figure 2.3). The intervening terrain is flat and relatively open. Wind from the SSW occurs most frequently. Another residence lies closer to the stack, 0.5 km WNW, but because it is located in Drip Springs Hollow at an elevation about 90 m below the top of the stack, airborne concentrations at this home are expected to be lower. In addition, the wind frequency in this direction is less than that from the SSW.

Calculation of the annual average air concentrations is given in Appendix 4 and the method of estimating dose to the limiting receptor is described in Appendix 5. Most dose to the body from airborne concentrations of the principal radionuclides discharged from the evaporator results from inhalation of particles and tritiated water vapor. Dose calculations are dependent on the degree of solubility of the radionuclide in the effluent, as indicated by stack measurements (see Section 2.6.2). Tritium, $^{90}$Sr and $^{137}$Cs were predominantly soluble, and, since $^{60}$Co and plutonium were both dissolved and associated with particles, dose was determined for each form. Their actual dose contribution lies between the calculated values, depending on the relative amounts that are soluble and insoluble.

Dose rates received by the limiting receptor from exposure by inhalation of airborne concentrations of these radionuclides are estimated to be:

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*The limiting receptor is defined as that person(s) who resides near the site and is most likely to receive the highest dose from operations of the facility.

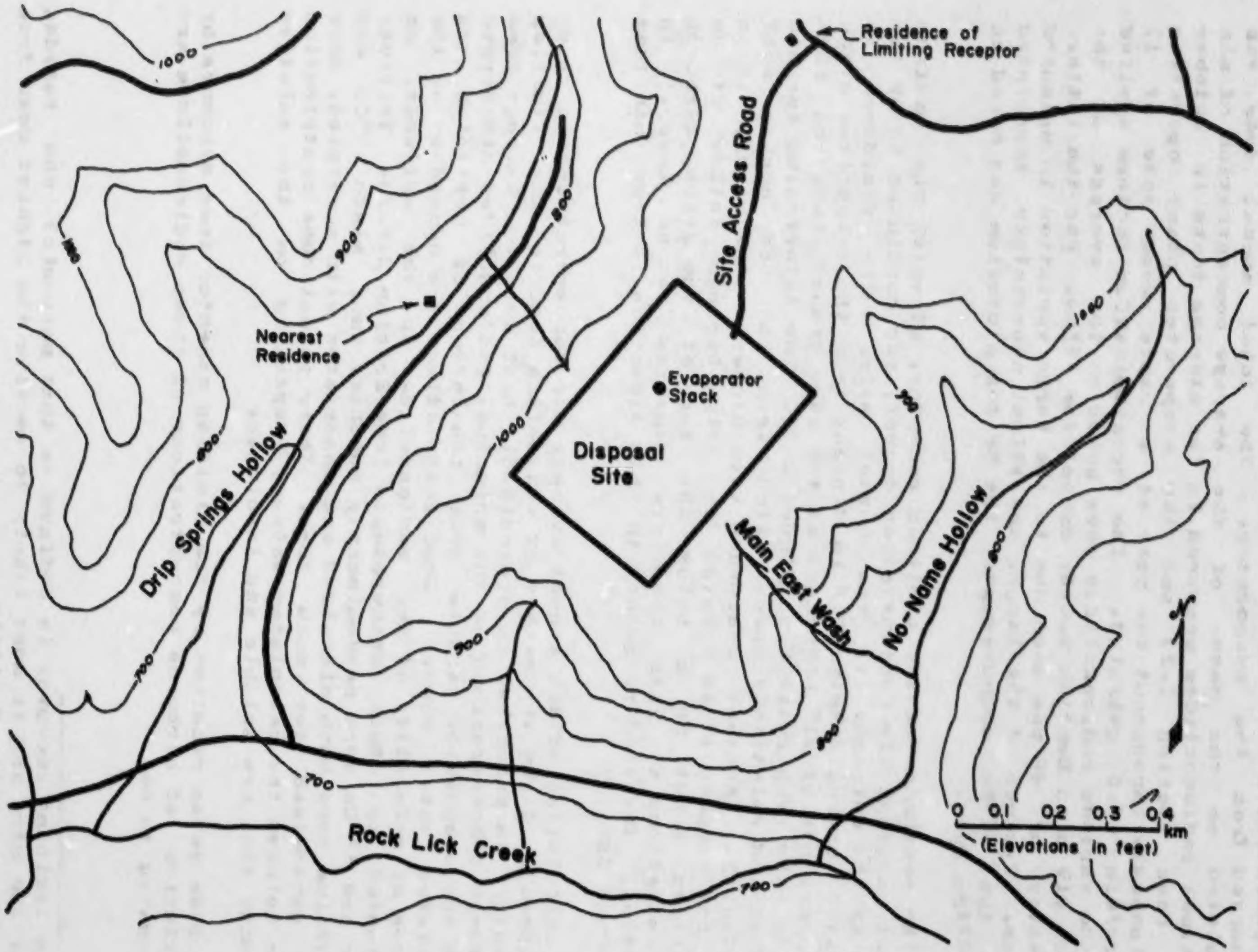

Figure 2.3 Locations of Residences near Evaporator Stack

| **Radionuclide** | **Form** | **Critical organ** | **Dose, mrem/yr** |
|---|---|---|---|
| $^{3}$H | soluble | total body | 2.6 |
| $^{60}$Co | soluble | GI tract | $1.4 \times 10^{-4}$ |
| | insoluble | lung | $5.0 \times 10^{-3}$ |
| $^{90}$Sr | soluble | bone | $7.1 \times 10^{-2}$ |
| $^{137}$Cs | soluble | total body | $3.8 \times 10^{-2}$ |
| $^{238}$Pu | soluble | bone | $1.0 \times 10^{-2}$ |
| | insoluble | lung | $6.2 \times 10^{-4}$ |
| $^{239}$Pu | soluble | bone | $5.4 \times 10^{-4}$ |
| | insoluble | lung | $2.8 \times 10^{-5}$ |

Of these radionuclides, $^{3}$H contributes the largest dose, estimated to be about 2.6 mrem/year to the limiting receptor, while the other above radionuclides individually contribute less than 1 mrem/year. To determine the total dose from the effluent, other radionuclides observed in the various tests must be considered. Of these, $^{226}$Ra and $^{228}$Ra may be the most significant.

It should also be noted that the calculational method used yields maximum annual dose rates. The actual dose should be factored on the bases of:

1. actual duration of year in which evaporator plant is operated, since it is shut down frequently for operational reasons and occasionally for repair,

2. volume of dilution water rather than waste being treated annually, and

3. duration of year that receptor lives in or near residence, and the actual airborne concentrations occurring within the home, particularly when it is closed to the outside.

In addition, comprehensive meteorological data for Maxey Flats are needed to determine more accurately annual average airborne concentrations. These data include frequency of wind speed and direction and of atmospheric stability conditions. Meteorological studies are also necessary to determine plume rise caused by its higher temperature relative to ambient air temperature, and the downwash effect on the plume induced by site structures.

## 3. ENVIRONMENTAL MEASUREMENTS

Radiological measurements described in this section were directed to identifying and measuring radionuclides in environmental media near the site. All sampling locations were outside the exclusion fence (unrestricted area) although some locations were within the site property boundary. The topography of the site and surrounding area is described in Section 1. Primary emphasis was placed on identifying and evaluating potentially significant pathways of radiation exposure to people living near the site. Pathways believed to be of secondary importance, e.g., tobacco, wild game, etc., were not examined.

### 3.1 Sample Collection and Analyses

Samples that were collected in the vicinity of the Maxey Flats site during the study period, October 1974 to August 1975, included surface water, stream bed sediment, domestic well water, milk and vegetables. The sampling locations are described in Table 3.1 and shown in Figures 3.1, 3.2 and 3.3. A summary of samples collected during the study is given in Appendix 6. Radionuclide analyses of samples included $^{3}H$ (HTO), $^{90}Sr$, gamma-ray-emitting radionuclides (gamma-ray spectrometry), $^{226}Ra$, $^{228}Ra$, $^{238}Pu$ and $^{239}Pu$. Details regarding sample preparation and radioassay of various types of samples are given in Appendix 7.

Four-liter grab samples of surface water and domestic well water were collected on October 7, 1974, and November 7, 1974. The samples were returned to the laboratory and filtered through Whatman #40 filter paper (2 µm). Analyses of the filtrates included $^{3}H$ (HTO), $^{90}Sr$ and gamma-ray-emitting radionuclides. Additional surface water samples, collected on March 13, 1975, included two 8-liter samples and one 30-liter sample. The suspended sediment from the 30-liter sample was separated after settling for one week and processed in the same manner as stream bed sediments. Larger volumes of domestic well water were collected on April 20, 1975, and August 26-27, 1975, for more sensitive analyses. Twenty-five-liter samples were acidified to pH 2 with concentrated HCl at the time of collection. Twenty-liter portions were analyzed for gamma-ray-emitting radionuclides after preconcentration by ion exchange, and four-liter aliquots were used for $^{90}Sr$ analysis. Radium-226 and $^{228}Ra$ were determined in 4-liter aliquots of samples collected on April 29, 1975.

Four-liter milk samples were obtained from dairy farms and family cows on two occasions, June 3, 1975, and August 26-27,

## Table 3.1

## Sampling Locations near Maxey Flats Burial Site

| Site Number | Location |
|---|---|
| 1-6 | Main East Wash |
| 7 | Wash NE of site |
| 8-10 | No-Name Hollow Creek |
| 11-16 | Rock Lick Creek - downstream from confluence with No-Name Hollow Creek |
| 17 | Fox Creek - near confluence with Rock Lick Creek |
| 18 | Fox Creek - 100 m upstream from confluence with Licking River (not shown in Figure 3.2) |
| 19-22 | Drip Springs Hollow |
| 23 | Pond near residence in Drip Springs Hollow |
| 24 | Farm pond in Drip Springs Hollow |
| 25 | Wash NW of site |
| 26 | Wash south of site |
| 27-28 | Fox Creek - upstream from confluence with Rock Lick Creek |
| 29-30 | Crane Creek |
| 31 | Rock Lick Creek - upstream from confluence with No-Name Hollow Creek |
| 32-33 | Farm ponds - near Maxey Flats Road, approximately 1.3 km east of site entrance |
| 34 | Pond on site property - outside exclusion fence, east of the site |
| 35 | Fox Creek - 25 m upstream from confluence with Licking River (not shown in Figure 3.2) |
| 36 | Farm pond - near junction of site access road and Maxey Flats Road |
| 37 | Wash on west side of site near the exclusion fence |
| 38 | Wash on west side of site approximately 25 m below site 37 |
| 39 | Rock Lick Creek - south of farm house on Rock Lick Creek road, approximately 0.3 km east of Rt. 158 |
| 40 | Residence in Drip Springs Hollow, approximately 0.5 km west of site evaporator |
| 41 | Residence on Rock Lick Creek road, approximately 1.7 km west of Rt. 158 |
| 42 | Abandoned house on Rock Lick Creek road, approximately 2.5 km west of Rt. 158 |
| 43 | Residence on Rock Lick Creek road, approximately 3.2 km west of Rt. 158 |
| 44 | Residence approximately 2.2 km north northeast of site, and approximately 0.3 km south of Rt. 32 |
| 45 | Pasture located south of Maxey Flats Road and east of the site access road |
| 46 | Dairy farm on Rock Lick Creek road approximately 0.3 km east of Rt. 158 |
| 47 | Dairy farm on Markwell Road approximately 3.1 km south southwest of the site |
| 48 | Residence southwest of the intersection of the site access road with Maxey Flats Road |
| 49 | Dairy farm approximately 11 km west of site (not shown on Figure 3.3) |
| 50 | Dairy farm on Rt. 158 approximately 3.1 km south southeast of the site |
| 51 | Residence on Maxey Flats Road approximately 1.1 km east of site access road |
| 52 | Residence on Maxey Flats Road approximately 1.0 km west of site access road |
| 53 | Garden near NECO operations office |

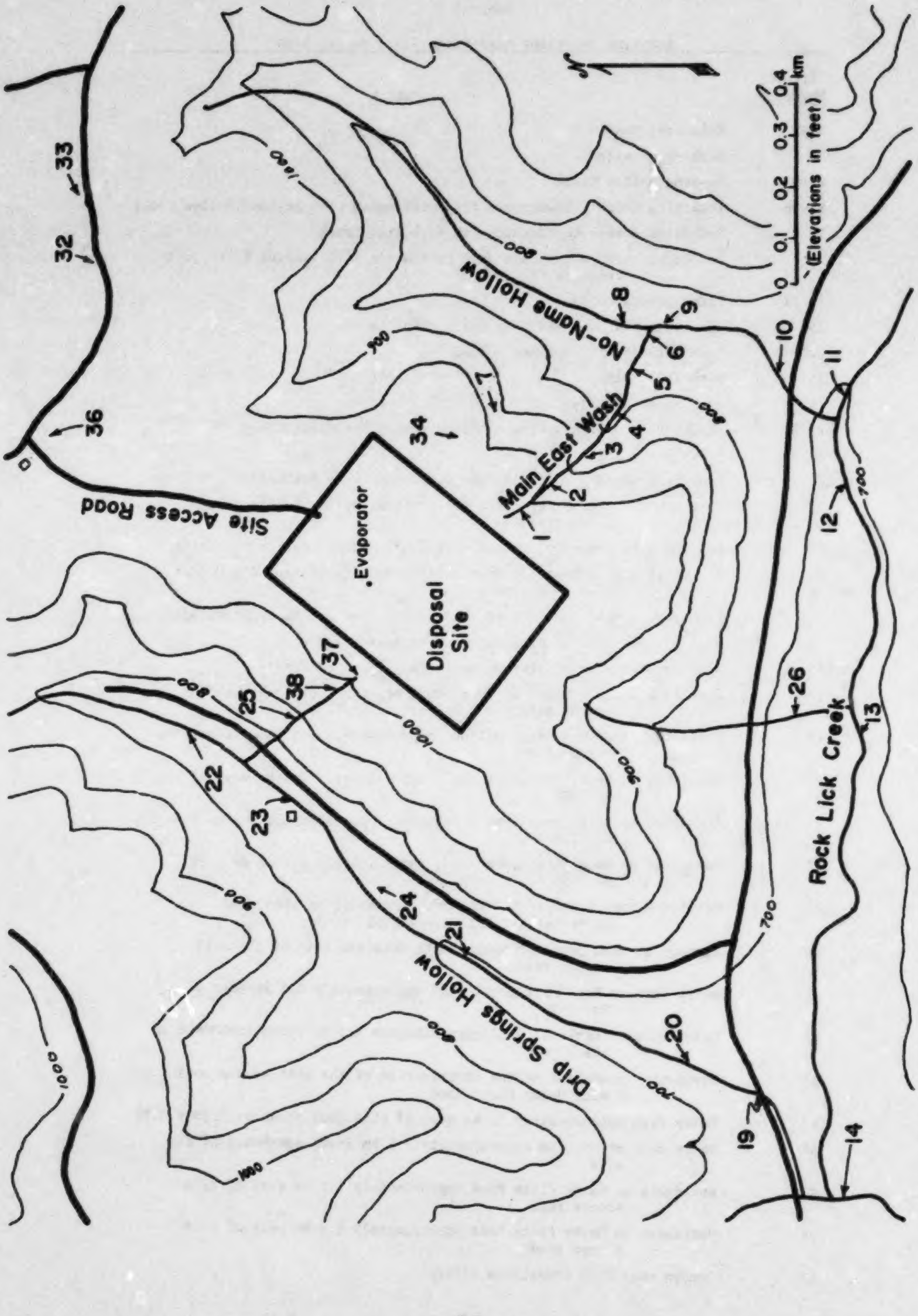

Figure 3.1 Nearby Surface Water and Sediment Sampling Locations

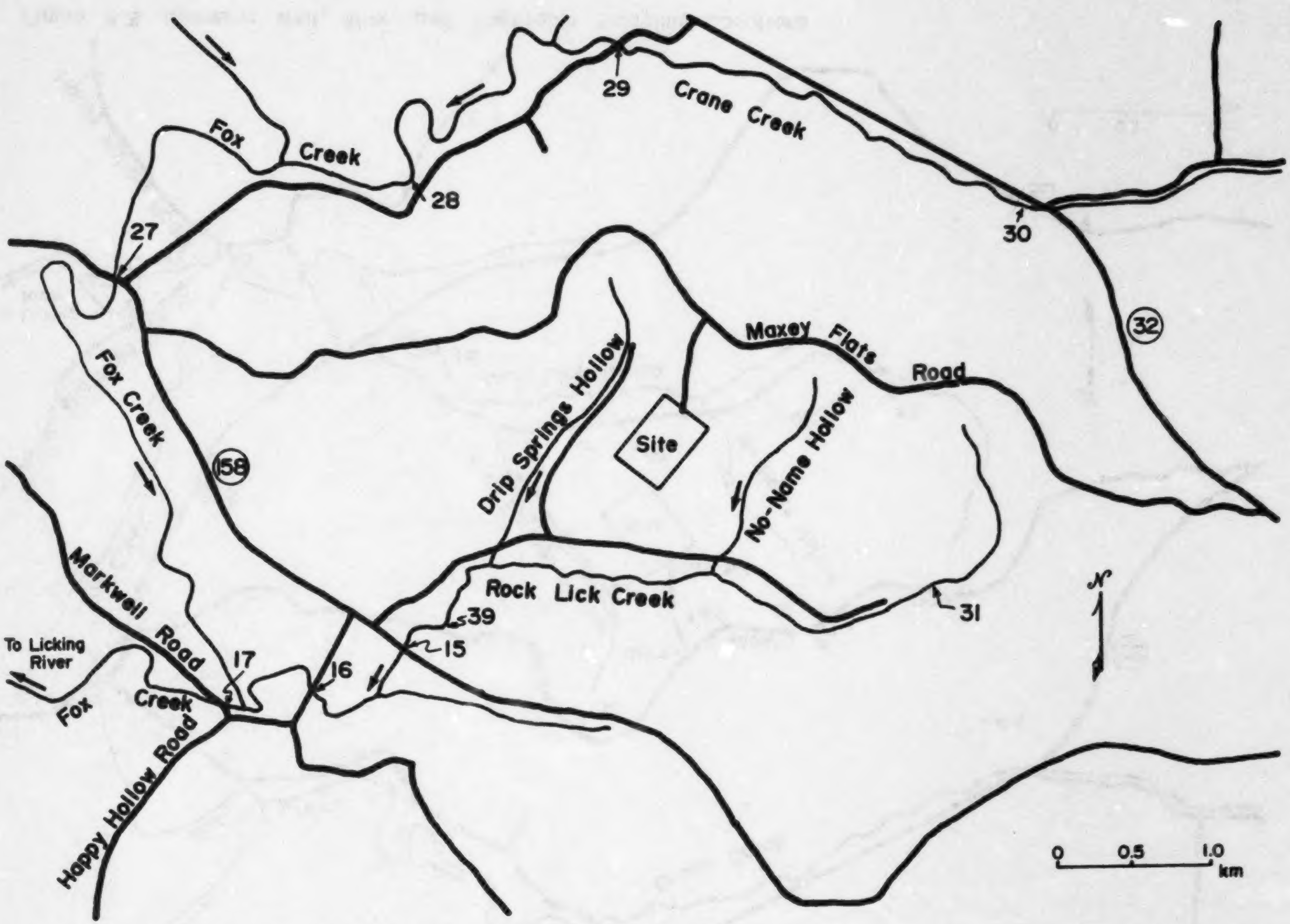

Figure 3.2 Distant Surface Water and Sediment Sampling Locations

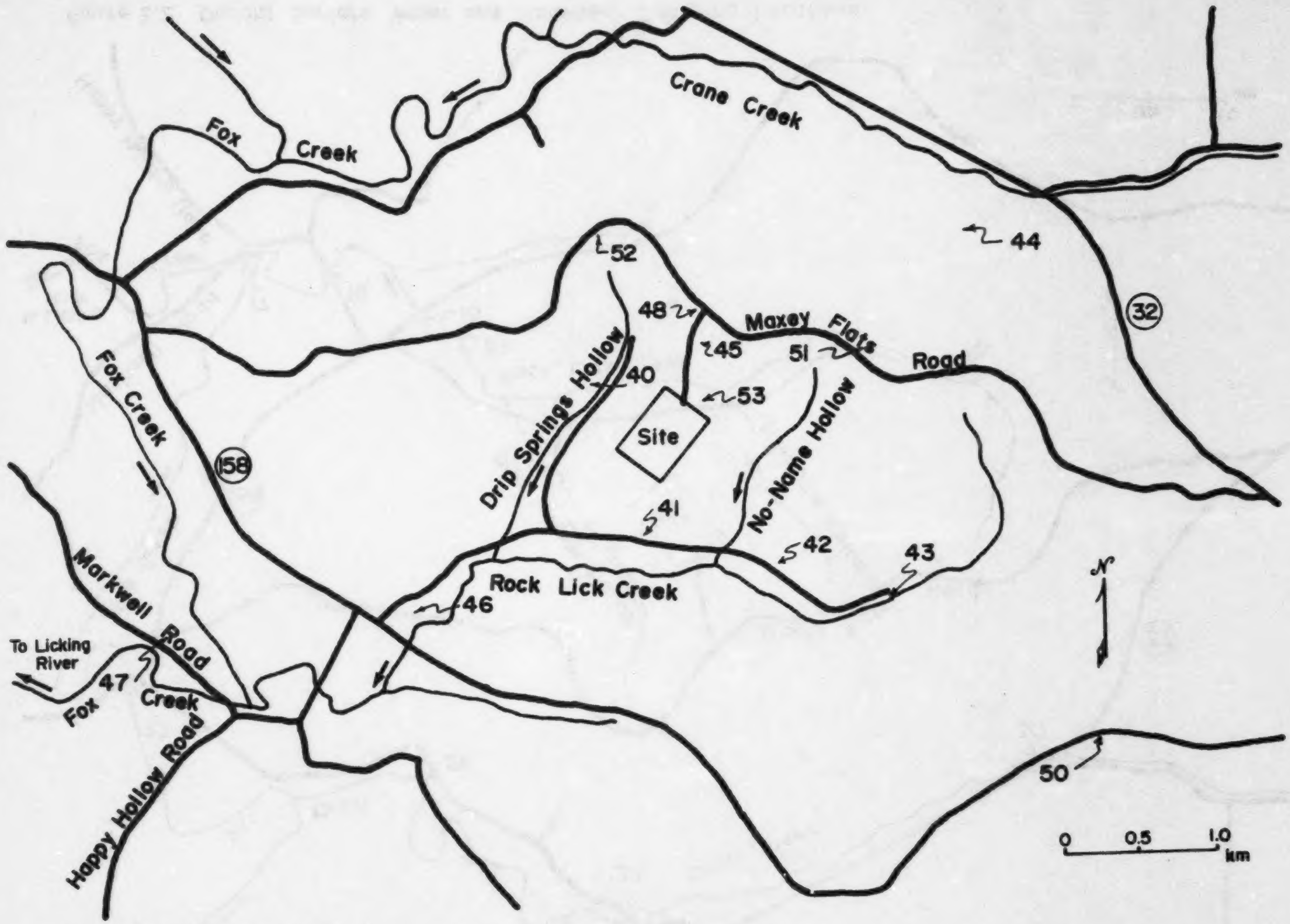

Figure 3.3 Domestic Well, Milk, and Vegetable Sampling Locations

1975. Radiochemical analyses of milk included $^{3}H$ (HTO), $^{90}Sr$ and gamma-ray spectrometry. At some milk sampling locations, samples of the cows' drinking water were collected for $^{3}H$ analyses.

Produce from vegetable gardens in the vicinity of Maxey Flats were collected during a field trip on August 26-27, 1975. Tomatoes were collected at seven locations; grapes, cucumbers, corn and watermelons were collected at four locations. All vegetable samples were analyzed for $^{3}H$ (HTO) and gamma-ray-emitting radionuclides. Samples from selected locations were also analyzed for $^{90}Sr$.

Stream bed sediments near the site were collected on October 7, 1974, November 11, 1974, April 29, 1975, and June 2, 1975, by removing the upper 1-2 cm of bed material with a small garden trowel. Sediments were taken from low points in the stream channels. Radiochemical analyses of sediment samples included gamma-ray spectrometry and, on selected samples, $^{90}Sr$, $^{238}Pu$ and $^{239}Pu$.

### 3.2 Radionuclides in Surface Water and Stream Bed Sediment

The principal drainage ways for surface run-off from the burial site are washes to the east and west of the site (see Figure 3.1). Water flow in both washes is intermittent since the primary water source is precipitation; however, pools are generally present even during relatively dry periods. Possible sources of radioactivity in surface water include contaminated water from the site surface, lateral movement of radioactive leachate from the trenches through the shallow soil zone, and subsurface migration from the trenches through fissure systems in the rock. Potential sources of surface contamination are spills during burial operations and pumping of the trenches, deposition of radioactivity from the evaporator plume, and overflow or lateral movement of leachate from the trenches to the surface. Contamination of stream bed sediment can result from the deposition of radionuclides associated with suspended sediment in surface water or adsorption of radionuclides from the water.

Surface water and stream bed sediment sampling was performed to identify and measure radionuclides moving from the burial site in order to evaluate potential aquatic pathways that could lead to exposure of people and the adequacy of the current environmental monitoring program. Since surface water from the site may include radionuclides from several sources which are affected by site operations and meteorological and climatic conditions, measurements made during this study should not be considered to represent conditions prevailing at all times. The routine environmental monitoring program should provide the data needed to determine any long-term trends.

3.2.1 Radionuclides in surface water. Initial sampling of surface water during the period of October 7-8, 1974, involved simultaneous sampling with KDHR and NECO for an interlaboratory comparison of $^3$H analyses. (The results of the interlaboratory comparison analyses were supplied to KDHR and NECO, and are not presented in this report.) The samples were collected during a relatively dry period with the last precipitation (3 cm) occurring on September 30, 1974, 7 days prior to sampling. Since flow rates in the creeks were low, samples from the washes were collected from pools. Water sampled from the washes during this period probably represents surface run-off from the last rainfall or flow from near-surface sources, since specific conductance measurements in streams during low flow show relatively small contributions from deep subsurface sources.(9)

The results of the radiochemical analyses are given in Table 3.2. Radionuclides detected in the surface water included $^3$H (HTO), $^{60}$Co and $^{90}$Sr. Tritium concentrations ranged from nondetectable (<200 pCi/l) to 15,200 pCi/l. Among the streams draining the site and ultimately emptying into Rock Lick Creek, the highest $^3$H concentration was in a wash east of the site (referred to as the Main East Wash). This wash, the principal drainage path for surface run-off from precipitation, has been estimated to receive approximately 75 percent of the total site run-off.(9) Tritium concentrations at locations upstream from the outfall of site drainage (27, 28, 29, 30, 31) were <240 pCi/l which indicates that site drainage is the principal source of $^3$H discharged to Rock Lick Creek and ultimately to Fox Creek. Cobalt-60 was the only gamma-ray emitter detected in surface water. Concentrations of $^{60}$Co were 5 pCi/l in the Main East Wash (Location 3), 3 pCi/l in Rock Lick Creek (Location 16), and below the minimum detectable level at all other locations.

Strontium-90 concentrations ranged from 0.9 to 80 pCi/l, with the highest concentration in the Main East Wash (Location 3). The $^{90}$Sr concentration in Drip Springs Hollow Creek (Locations 19 and 22) was only 0.9 pCi/l compared to 5.2 pCi/l in Rock Lick Creek at Location 15 just below the outfall of Drip Springs Hollow Creek. This suggests that for this particular sampling period, the Main East Wash was the principal source of $^{90}$Sr released to Rock Lick Creek. Strontium-90 concentrations in No-Name Hollow Creek (Location 10) and Rock Lick Creek (Location 15) were 5.0 and 5.2 pCi/l, respectively, which are lower than expected considering the $^{90}$Sr concentration in the Main East Wash and the expected dilution factors, approximated from $^3$H measurements. This can be attributed to deposition from the water onto the stream sediment. The contribution of atmospheric fallout to the $^{90}$Sr levels in surface water was not measured, however, an upper limit of 1 to 2 pCi/l can be inferred from the $^{90}$Sr concentrations in Drip Springs Hollow Creek at Locations 19 and 22. This represents an upper limit since site releases could contribute to the measured values at these locations.

The surface water samples collected on November 7, 1974, were taken in conjunction with sediment sampling to trace the movement

Table 3.2

Radionuclide Concentrations in Environmental Water Samples, Oct. 7-8, 1974

| Location no. | Description | Radionuclide concentration, pCi/l | | |
|---|---|---|---|---|
| | | $^{3}$H | Gamma-ray emitters | $^{90}$Sr |
| 3 | Main East Wash | 1.33 ± 0.03(4) | $^{60}$Co - 5 ± 2 | 80 ± 3 |
| 10 | No-Name Hollow Creek | 9.2 ± 0.2(3) | ND | 5.0 ± 0.3 |
| 31 | Rock Lick Creek | <0.2(3) | ND | <0.6 |
| 15 | Rock Lick Creek | 1.5 ± 0.2(3) | ND | 5.2 ± 0.6 |
| 16 | Rock Lick Creek | 0.7 ± 0.2(3) | $^{60}$Co - 3 ± 2 | NA |
| 17 | Fox Creek | 0.4 ± 0.2(3) | ND | 2.1 ± 0.3 |
| 26 | Run-off south of site | 3.2 ± 0.2(3) | ND | NA |
| 19 | Drip Springs Hollow Creek | 4.7 ± 0.2(3) | ND | 0.9 ± 0.2 |
| 22 | Drip Springs Hollow Creek | 2.2 ± 0.2(3) | ND | 0.9 ± 0.1 |
| 23 | Old pond on McRoberts Farm | 1.52 ± 0.02(4) | ND | NA |
| 24 | New pond on McRoberts Farm | 8.5 ± 0.2(3) | ND | NA |
| 27 | Fox Creek | 0.2 ± 0.1(3) | ND | NA |
| 28 | Fox Creek | <0.2(3) | ND | NA |
| 29 | Crane Creek | 0.2 ± 0.1(3) | ND | NA |
| 30 | Crane Creek | 0.2 ± 0.1(3) | ND | 2.0 ± 0.2 |
| 35 | Fox Creek at confluence with Licking River | <0.2(3) | ND | NA |

Notes:

1. ND - not detected; typical detection limits were: $^{60}$Co 3 pCi/l, $^{137}$Cs 3 pCi/l.
2. NA - not analyzed.
3. ± values are uncertainties based on 2σ counting error.
4. Exponents of 10 are indicated in parentheses; 1.33 ± 0.03(4) = (1.33 ± 0.03) x $10^4$.

of radionuclides along the main drainage pathway. Samples were taken in the Main East Wash, No-Name Hollow Creek, and Rock Lick Creek. Approximately 1.3 cm (0.5 in) of precipitation had fallen intermittently during the three days preceeding sample collection, and water was flowing in the Main East Wash and surrounding creeks. The radionuclide concentrations are given in Table 3.3. Tritium concentrations in the Main East Wash ranged from 28,500 to 45,000 pCi/l, and generally decreased going down the wash. One sample collected at Location 3 was from a spring located approximately 1 m above the main stream bed. The $^3$H concentration of the spring water was much lower (6000 pCi/l) than stream water in the Main East Wash (41,600 pCi/l). Although the spring water could be contaminated by both subsurface migration and surface run-off, its low $^3$H concentration relative to stream water in the Main East Wash suggests that the subsurface pathway for $^3$H was small compared to surface run-off. Supporting this conclusion are the generally decreasing $^3$H concentrations in the series of samples collected from the top to the bottom of the wash. The decreasing trend suggests that $^3$H from the surface of the burial site was progressively diluted going down the wash. This does not exclude the possibility of contributions of contaminated ground water via subsurface migration through the deep geologic zones, but suggests that the latter pathway was not a significant contributor during this sampling period.

The $^3$H concentration in No-Name Hollow Creek upstream from the confluence with the Main East Wash (Location 8) was approximately an order of magnitude lower than below the confluence (Location 10). The $^3$H concentration at Location 9 appears anomalous since it is lower than at Location 10 and in Rock Lick Creek (Locations 12, 13, 14). Tritium concentrations in Rock Lick Creek decreased from 4700 pCi/l at Location 12 near the confluence of No-Name Hollow Creek and Rock Lick Creek to 1900 pCi/l at Location 16, which is approximately 3.2 km downstream from Location 12. The $^3$H concentrations in two farm ponds approximately 0.9 km NE of the site (Locations 32, 33) were 600 and 400 pCi/l, respectively. Tritium levels in excess of ambient, assumed to be 200 pCi/l or less, is attributed to depletion from the evaporator plume since surface run-off from the site could not reach these ponds.

The only gamma-ray emitters detected in surface water were $^{60}$Co (Location 3) and $^{103}$Ru (Location 34), at concentrations of 3 pCi/l and 9 pCi/l, respectively. The presence of the short-lived $^{103}$Ru (half-life of 40 days) detected in a pond (Location 34) was most likely from surface run-off. The highest $^{90}$Sr concentrations in the various streams were: 68 pCi/l in the Main East Wash (Location 2), 5.8 pCi/l in No-Name Hollow Creek (Location 10), and 5.8 pCi/l in Rock Lick Creek (Location 12). As observed in the October 7-8, 1974, samples, the $^{90}$Sr concentrations in No-Name Hollow Creek and Rock Lick Creek were lower than might be expected from its concentration in the Main

Table 3.3

Radionuclide Concentrations in Environmental Water Samples, Nov. 7, 1974

| Location no. | Description | Radionuclide concentration, pCi/l |  |  |
|---|---|---|---|---|
|  |  | $^{3}$H | Gamma-ray emitters | $^{90}$Sr |
| 1 | Main East Wash | 3.5 ± 0.1(4) | ND | 68 ± 3 |
| 2 | Main East Wash | 4.5 ± 0.1(4) | ND | 44 ± 2 |
| 3 | Main East Wash (spring water & runoff) | 4.2 ± 0.1(4) | ND | NA |
| 3 | Main East Wash (spring water) | 6.0 ± 0.3(3) | $^{60}$Co - 3 ± 2 | NA |
| 3-A | Main East Wash (15 ft. below 3) | NA | ND | NA |
| 4 | Main East Wash | 2.85 ± 0.05(4) | ND | 53 ± 1 |
| 5 | Main East Wash | 3.05 ± 0.05(4) | ND | 64 ± 3 |
| 6 | Main East Wash | 2.88 ± 0.04(4) | ND | NA |
| 8 | No-Name Hollow Creek | 1.4 ± 0.2(3) | ND | NA |
| 9 | No-Name Hollow Creek | 1.8 ± 0.2(3) | ND | 1.8 ± 0.4 |
| 10 | No-Name Hollow Creek | 1.38 ± 0.03(4) | ND | 6 ± 2 |
| 11 | Rock Lick Creek | 0.5 ± 0.2(3) | ND | 2.3 ± 0.3 |
| 12 | Rock Lick Creek | 4.7 ± 0.2(3) | ND | 5.8 ± 0.2 |
| 13 | Rock Lick Creek | 4.6 ± 0.2(3) | ND | 2.1 ± 0.1 |
| 14 | Rock Lick Creek | 3.7 ± 0.2(3) | ND | 1.9 ± 0.2 |
| 15 | Rock Lick Creek | 3.9 ± 0.2(3) | ND | 2.6 ± 0.2 |
| 16 | Rock Lick Creek | 1.9 ± 0.2(3) | ND | 1.9 ± 0.2 |
| 32 | Farm pond | 0.6 ± 0.2(3) | ND | NA |
| 33 | Farm pond | 0.4 ± 0.2(3) | ND | NA |
| 34 | Pond near site boundary | 3.0 ± 0.2(3) | $^{103}$Ru - 9 ± 4 | NA |

Notes:

1. ND - not detected; typical detection limits were: $^{60}$Co 3 pCi/l, $^{137}$Cs 3 pCi/l.
2. NA - not analyzed.
3. ± values are 2σ uncertainties based on counting error.
4. Exponents of 10 are indicated by numbers in parentheses; 3.53 ± 0.06(4) = (3.53 ± 0.06) x $10^{4}$.

East Wash and the estmated dilution in No-Name Hollow Creek and Rock Lick Creek. As explained earlier, this is most likely due to the $^{90}Sr$ depositing on sediments.

The radionuclide concentrations in the two 8-liter samples from a wash west of the trench area (Locations 37, 38) and one 30-liter sample from the Main East Wash (Location 5), collected on March 13, 1975, are presented in Table 3.4. In addition, sediment from 20 liters of the water collected at Location 5 was separated for analyses of gamma-ray emitters and plutonium. The $^{3}H$ concentrations in the wash west of the trench area were 179,000 pCi/l at Location 37 and 82,400 pCi/l at Location 38 compared to 12,700 pCi/l in the Main East Wash (Location 5). The high concentrations in the west wash compared to the Main East Wash suggest that the depletion of $^{3}H$ from the evaporator plume may contribute significantly to the levels observed in surface run-off. The samples were collected during a period of heavy rainfall (March 11-13) with 5 to 10 knot winds varying from the north-northeast to east. Strontium-90 concentrations in the wash west of the trench area were 16.1 pCi/l at Location 37 and 6 pCi/l at Location 38 compared to 14.3 pCi/l in the Main East Wash at Location 5. It should be noted in making the previous comparisons that the drainage volume to the east wash is much greater than that to the west. Hence the comparison does not relate the total radioactivity in the two washes, however, during this period both washes were significant pathways for carrying $^{3}H$ and $^{90}Sr$ from the site.

Analysis of the larger water volumes (8 to 30 liters) provided the sensitivity required to measure the following gamma-ray emitters: $^{60}Co$, $^{95}Zr$, $^{95}Nb$, $^{103}Ru$, $^{131}I$, andd $^{137}Cs$. The concentrations were quite low and of little significance compared to the $^{3}H$ and $^{90}Sr$ levels. Since ground water movement is usually much slower than surface water movement, the presence of relatively short-lived radionuclides, particularly $^{95}Zr$ (half-life of 65.5 d), $^{103}Ru$ (half-life of 39.8 d), and $^{131}I$ (half-life of 8.06 d), indicates that surface run-off from the burial site is a major source of radioactivity leaving the site. Radionuclides in sediment from water collected at Location 5 included $^{60}Co$, $^{95}Zr$, $^{95}Nb$, $^{134}Cs$, and $^{137}Cs$, all at concentrations less than 1 pCi/l. With the exception of $^{95}Zr$, more activity was associated with the sediment than with the water. This could result from transport of contaminated sediment in the stream beds draining the site.

During the period of October 1974 to March 1975, $^{3}H$ and $^{90}Sr$ were the only radionuclides of radiological significance detected in surface water. The highest $^{3}H$ concentration (179,000 pCi/l) occurred in a sample from the wash west of the site and this level corresponded to 6 percent of the MPC for $^{3}H$ in unrestricted areas.(22) The highest $^{90}Sr$ concentration (80 pCi/l) was in a sample from the Main East Wash and corresponded to 27 percent of the MPC for $^{90}Sr$. The $^{3}H$ and $^{90}Sr$ concentrations were

Table 3.4

Radionuclide Concentrations in Large Volume Environmental Water Samples, March 13, 1975

| Location no. | Description | Radionuclide concentration of water, pCi/l | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | $^{3}H$ | $^{60}Co$ | $^{90}Sr$ | $^{95}Nb$ | $^{95}Zr$ | $^{106}Ru$ | $^{137}Cs$ |
| 37 | Wash on west side of site (opposite the evaporator, near site boundary | 1.79 ± 0.09(5) | 0.6 ± 0.2 | 16.1 ± 0.2 | 0.9 ± 0.3 | <0.6 | <0.4 | 0.2 ± 0.1 |
| 38 | Wash on west side of site (opposite evaporator, approximately 20 ft. below top of Ohio shale) | 8.24 ± 0.06(4) | 0.8 ± 0.3 | 6.0 ± 0.1 | 0.8 ± 0.4 | <0.6 | <0.4 | <0.1 |
| 5 | Main East Wash at logging road* | 1.27 ± 0.03(4) | 0.2 ± 0.1 | 14.3 ± 0.3 | 0.3 ± 0.1 | 4.7 ± 0.5 | 1.1 ± 0.2 | <0.1 |
| | | Radionuclide concentration of suspended sediment, pCi/g and (pCi/l)** | | | | | | |
| | | $^{60}Co$ | $^{95}Nb$ | $^{95}Zr$ | $^{134}Cs$ | $^{137}Cs$ | $^{238}Pu$ | $^{239}Pu$ |
| 5 | Main East Wash at logging road | 3.5 ± 0.4<br>(0.70 ± 0.08) | 3.0 ± 0.5<br>(0.60± 0.01) | 2.0 ± 0.7<br>(0.40± 0.01) | 0.5 ± 0.3<br>(0.10± 0.06) | 2.7 ± 0.3<br>(0.50± 0.06) | 0.70 ± 0.07<br>(0.14 ± 0.01) | 0.33 ± 0.04<br>(0.07 ± 0.01) |

* $^{131}I$ detected at 0.4 ± 0.2 pCi/l.

** Sediment concentrations in parentheses is pCi/l calculated from pCi/gram sediment x $\frac{\text{grams sediment}}{\text{liter of water}}$ = pCi/g x 0.2 g/l.

Notes:

1. ± values are 2σ are uncertainties based on counting errors.
2. Exponents of 10 are indicated by numbers in parentheses; 1.79 ± 0.09(4) = (1.79 ± 0.09) x $10^4$.

considerably lower in Rock Lick Creek where the highest measured concentrations were 4700 pCi/l and 5.8 pCi/l, respectively.

The surface water measurements suggest that the radioactivity detected in Rock Lick Creek resulted principally from surface run-off, but do not indicate the source of the surface contamination. A comprehensive assessment of the radiological impact of radionuclides entering Rock Lick Creek from the site would require an estimate of the quantity of radioactivity that is transported down the various drainage pathways. This would necessitate continuous flow measurements and sampling of the major drainage pathways. In view of the observed $^{3}H$ and $^{90}Sr$ concentrations in site run-off, the site monitoring program should be expanded to monitor the quantities of these radionuclides entering Rock Lick Creek. Specific recommendations regarding surface water monitoring are given in Section 5. Additional hydrological, geological and radiological measurements would be necessary to determine the relative significance of the various sources of the radioactivity observed in surface run-off.

3.2.2 Radionuclides in stream bed sediment. Sediment samples from stream beds were collected from pathways draining the site: No-Name Hollow Creek, Drip Springs Hollow Creek and Fox Creek. Most samples were collected during the field trip of November 7-8, 1974, to identify and measure radionuclides in the Main East Wash, No-Name Hollow Creek, and Rock Lick Creek. To determine the extent of radionuclide transport via the other drainage pathways, additional sediment samples were collected on April 29, 1975, and June 3, 1975.

The results of the radiochemical analyses are given in Table 3.5 for all sediment samples collected during this study. These results show that radionuclides associated with burial operations were present in all sediment samples from streams receiving effluents discharged via the Main East Wash, as far distant as the confluence of Fox and Rock Lick Creeks. In addition to naturally-occurring radionuclides, $^{54}Mn$, $^{60}Co$, $^{90}Sr$, $^{137}Cs$, $^{238}Pu$ and $^{239}Pu$ were detected in sediment. The highest radionuclide concentrations were observed in the Main East Wash. Similar to the surface water results, radionuclide concentrations generally decreased going down the principal drainage pathway: Main East Wash to No-Name Hollow Creek to Rock Lick Creek. The $^{90}Sr$, $^{137}Cs$, $^{238}Pu$ and $^{239}Pu$ concentrations in sediments from streams receiving site effluents were generally higher than in sediment from streams isolated from site effluents, suggesting that the contribution of atmospheric fallout from nuclear detonations was small. Since $^{60}Co$ is undetectable in atmospheric fallout, its presence in sediment gave unambiguous evidence that disposal operations have resulted in off-site contamination.

Cobalt-60 levels in sediment in the main drainage pathway generally decreased with increasing distance from the site, ranging from 4.3 to 2.7 pCi/g in the Main East Wash, 2.3 to 1.7

Table 3.5

Radionuclide Concentrations in Sediment Samples From the Maxey Flats Environment

| Location no. | Date sampled | Description | Radionuclide concentration, pCi/g (Dry Weight) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | $^{54}$Mn | $^{60}$Co | $^{90}$Sr | $^{137}$Cs | $^{226}$Ra | $^{238}$Pu | $^{239}$Pu |
| 1 | 11/7/74 | Main East Wash | <0.05 | 4.3 ± 0.1 | 2.3 ± 0.1 | 1.28 ± 0.05 | 2.8 ± 0.5 | NA | NA |
| 3 | 10/7/74 | Main East Wash | 0.22 ± 0.05 | 3.5 ± 0.1 | 2.8 ± 0.1 | 1.61 ± 0.05 | 5.8 ± 0.6 | 0.82 ± 0.04 | 0.43 ± 0.03 |
| 3 | 11/7/74 | Main East Wash | <0.08 | 4.3 ± 0.1 | 4.1 ± 0.1 | 1.58 ± 0.05 | 7.5 ± 0.8 | 0.70 ± 0.05 | 0.44 ± 0.03 |
| 4* | 11/7/74 | Main East Wash | 0.23 ± 0.09 | 2.7 ± 0.2 | 42.5 ± 0.1 | 1.7 ± 0.1 | 3 ± 1 | NA | NA |
| 5 | 11/7/74 | Main East Wash | 0.09 ± 0.04 | 3.0 ± 0.1 | 3.3 ± 0.1 | 1.26 ± 0.06 | 4.8 ± 0.6 | NA | NA |
| 6 | 11/7/74 | Main East Wash | <0.05 | 1.43 ± 0.05 | 3.6 ± 0.1 | 0.70 ± 0.05 | 5.8 ± 0.5 | 0.58 ± 0.04 | 0.32 ± 0.03 |
| 7 | 11/7/74 | Wash NE of site | <0.04 | 0.21 ± 0.02 | 0.66 ± 0.05 | 2.02 ± 0.04 | 1.4 ± 0.4 | NA | NA |
| 8 | 11/7/74 | No-Name Hollow Creek | <0.05 | <0.04 | 0.2 ± 0.1 | 0.06 ± 0.02 | 10.2 ± 0.7 | <0.004 | <0.004 |
| 9 | 11/7/74 | No-Name Hollow Creek | <0.04 | 2.3 ± 0.1 | 1.2 ± 0.1 | 1.18 ± 0.07 | 8.5 ± 0.7 | 0.53 ± 0.04 | 0.27 ± 0.03 |
| 10 | 11/7/74 | No-Name Hollow Creek | <0.03 | 1.68 ± 0.03 | 0.5 ± 0.1 | 0.87 ± 0.02 | 9.2 ± 0.3 | NA | NA |
| 11 | 11/7/74 | Rock Lick Creek | <0.04 | <0.04 | 0.22 ± 0.07 | 0.11 ± 0.02 | 8.4 ± 0.7 | 0.008 ± 0.003 | 0.007 ± 0.003 |
| 12 | 11/7/74 | Rock Lick Creek | <0.07 | 1.24 ± 0.08 | 0.5 ± 0.1 | 0.60 ± 0.05 | 5.7 ± 0.7 | 0.25 ± 0.02 | 0.17 ± 0.02 |
| 12 | 6/3/75 | Rock Lick Creek | <0.03 | 0.08 ± 0.03 | NA | 0.08 ± 0.02 | 7.5 ± 0.6 | 0.018 ± 0.005 | 0.006 ± 0.002 |
| 13 | 11/7/74 | Rock Lick Creek | <0.05 | 1.12 ± 0.05 | 0.07 ± 0.05 | 1.11 ± 0.05 | 6.6 ± 0.6 | NA | NA |
| 14 | 11/7/74 | Rock Lick Creek | <0.02 | 0.17 ± 0.02 | 0.24 ± 0.08 | 0.31 ± 0.02 | 8.5 ± 0.2 | 0.083 ± 0.005 | 0.025 ± 0.003 |
| 15 | 11/7/74 | Rock Lick Creek | <0.03 | 0.25 ± 0.03 | 0.31 ± 0.08 | 0.26 ± 0.02 | 8.4 ± 0.5 | NA | NA |
| 16 | 11/7/74 | Rock Lick Creek | 0.06 ± 0.02 | 0.67 ± 0.04 | 0.24 ± 0.07 | 0.60 ± 0.03 | 5.8 ± 0.4 | 0.23 ± 0.02 | 0.07 ± 0.01 |
| 17 | 6/3/75 | Fox Creek | <0.02 | <0.04 | NA | 0.13 ± 0.03 | 5.1 ± 0.1 | <0.003 | <0.003 |
| 18 | 6/3/75 | Fox Creek | <0.02 | <0.04 | NA | 0.40 ± 0.03 | 3.6 ± 0.6 | NA | NA |
| 20 | 4/29/75 | Drip Springs Hollow | <0.02 | <0.04 | NA | <0.04 | 7.2 ± 0.1 | <0.001 | <0.001 |
| 21 | 4/29/75 | Drip Springs Hollow | <0.02 | <0.04 | NA | <0.04 | 7.7 ± 0.5 | NA | NA |
| 25 | 4/29/75 | Wash west of site | <0.02 | 1.36 ± 0.05 | NA | 0.98 ± 0.04 | 7.2 ± 0.5 | 0.09 ± 0.01 | 0.09 ± 0.01 |
| 26 | 10/7/74 | Wash south of site | <0.03 | 0.17 ± 0.03 | 0.21 ± 0.07 | 0.19 ± 0.02 | 3.6 ± 0.5 | 0.09 ± 0.01 | 0.005 ± 0.002 |
| 27 | 6/3/75 | Fox Creek | <0.03 | <0.04 | NA | 0.13 ± 0.03 | 4.2 ± 0.6 | NA | NA |

* Sample taken at Location 4 included leaves and sediment.

Notes: 1. ± values are 2σ uncertainties based on counting error; 2. NA - not analyzed.

pCi/g in No-Name Hollow Creek, and 1.2 to 0.08 pCi/g in Rock Lick Creek. Cobalt-60 was not detected (<0.04 pCi/g) in sediment from No-Name Hollow Creek upstream from the outfall of the Main East Wash (Location 8) or in sediment from Rock Lick Creek upstream from the confluence with No-Name Hollow Creek (Location 11), indicating that its major source was site effluents discharged via the Main East Wash. Similar trends were observed for $^{90}$Sr, $^{137}$Cs, $^{238}$Pu, and $^{239}$Pu. The $^{90}$Sr concentration in a sediment sample from Location 4 was 42.5 pCi/g, an order of magnitude higher than any other sample. This sample consisted of a mixture of dead leaves and sediment. The high $^{90}$Sr concentration can be attributed to the probable high ion-exchange capacity of organic material. The highest $^{238}$Pu and $^{239}$Pu concentrations in sediment, 0.82 and 0.43 pCi/g, respectively, occurred at Location 3 in the Main East Wash. Low-level plutonium concentrations (0.23 pCi $^{238}$Pu/g and 0.07 pCi $^{239}$Pu/g) were observed in sediment from Rock Lick Creek as far as Location 16, the last sampling location in Rock Lick Creek before it joins Fox Creek. Cobalt-60 was also detected in sediment from washes northeast (Location 7), west (Location 25), and south of the site (Location 26).

The only artificially-produced radionuclide detected in sediments from Fox Creek was $^{137}$Cs. Its presence, at very low concentrations (0.13 to 0.40 pCi/g), is considered to be from atmospheric fallout.

In contrast to surface water measurements which reflect conditions at the time of sampling, sediment measurements may reflect the accumulation of radioactivity from May 1963, when burial operations began, to the date of sample collection. Although radionuclide concentrations in stream bed sediment cannot be directly related to the quantity or concentration of radionuclides released to streams, their accumulation in sediment permit the detection of radionuclides previously released or that are present in very low concentrations in surface water.

The analyses of stream bed sediment showed that $^{60}$Co, $^{90}$Sr, $^{137}$Cs, $^{238}$Pu and $^{239}$Pu have moved from the burial site in sufficient quantities to be detected in the stream bed sediment of Rock Lick Creek as far as 3.5 km below the confluence of No Name Hollow Creek. In addition, $^{54}$Mn from the site was detected in the Main East Wash.

The radionuclide concentrations in sediment samples from the Main East Wash did not vary significantly from near the top to the bottom of the wash. This suggests that a major source of sediment contamination was from the surface of the burial site, presumably from the transport of contaminated soil or adsorption of radionuclides from surface water. Recently reported plutonium concentrations in soil core samples from the Main East Wash also suggest that a major source was the site surface.(2) The highest plutonium concentrations occurred in samples collected at the top of the wash near the fence and generally decreased at sampling locations down the Main East Wash.

Although both the surface water and sediment data indicate that a major source of the contamination detected in the site drainage and nearby streams was radioactivity transported from the site surface, this does not exclude some contribution from other pathways, such as subsurface migration from the trenches to the groundwater. Radionuclide measurements of surface water and sediment are of little value in detecting or assessing the contribution of subsurface migration from the trenches through soil and rock to the environment since the quantity of radionuclides from other sources appears to be greater and indistinguishable from that contributed by subsurface migration.

## 3.3 Radionuclides in Domestic Well Water

Families living south of the burial site receive their water supply from shallow wells that may contain radionuclides from the Maxey Flats waste burial site. To assess potential radiation dose to individuals drinking well water, five wells were monitored for radioactivity during this study. Four wells, Locations 40, 41, 42 and 43, are within 1.6 km of the site, and have been shown by KDHR to have elevated $^{3}$H (HTO) levels.(8) The fifth well at Location 44, approximately 2.2 km north-northeast of the burial site, is not affected by surface run-off from the site, although contamination by radionuclides from the site evaporator is possible.

Radionuclide concentrations of well water samples are given in Table 3.6. The detection limits for $^{90}$Sr and the gamma-ray emitters were much lower for samples collected on April 29, 1975, and August 26-27, 1975, because 20-liter samples were analyzed.

Tritium was the only radionuclide detected in well water samples at concentrations which reflect contributions from site operations. The $^{3}$H levels in well water from Locations 40 and 41 exceeded 1000 pCi/l on all three sampling dates, ranging from 1100 to 1900 pCi/l. At Location 43 the $^{3}$H concentration was 2000 pCi/l on October 7, 1974, but less than 200 pCi/l on April 29, 1975, and August 26, 1975. Location 43 is in an area where site run-off should not contaminate the well, and the high concentration on October 7, 1974, may reflect contributions from the evaporator. Lower concentrations, 500 to 700 pCi/l, were measured at Location 42, which is near an abandoned house and not a regular source of water for domestic use.

Although $^{90}$Sr was detected in well water at low concentrations (0.02 to 0.5 pCi/l), its source may be atmospheric fallout rather than site effluents.

Radium analyses of selected well water samples showed $^{226}$Ra concentrations ranging from 1.0 to 2.0 pCi/l and $^{228}$Ra

Table 3.6

Radionuclide Concentrations in Domestic Well Water Samples

From the Vicinity of the Maxey Flats Site

| | | Radionuclide concentration, pCi/1 | | | | | |
|---|---|---|---|---|---|---|---|
| | | | Gamma-ray emitters* | | | | |
| Location no. | Date sampled | $^{3}H$ | $^{60}Co$ | $^{137}Cs$ | $^{90}Sr$ | $^{226}Ra$ | $^{228}Ra$ |
| 40 | 10/7/74 | 1.1 ± 0.2(3) | < 3 | < 3 | NA | 1.0 ± 0.1 | <0.9 |
| | 4/29/75 | 1.9 ± 0.2(3) | <0.2 | <0.2 | 0.29 ± 0.03 | NA | NA |
| | 8/27/75 | 1.7 ± 0.1(3) | <0.2 | <0.2 | 0.13 ± 0.01 | NA | NA |
| 41 | 10/7/74 | 1.9 ± 0.2(3) | < 3 | <3 | NA | 2.0 ± 0.1 | <0.9 |
| | 4/29/75** | 1.6 ± 0.2(3) | <0.2 | <0.2 | 0.5 ± 0.1 | NA | NA |
| | 8/27/75 | 1.6 ± 0.1(3) | <0.2 | <0.2 | 0.07 ± 0.01 | NA | NA |
| 42 | 10/7/74 | 0.5 ± 0.2(3) | < 3 | <3 | NA | NA | NA |
| | 4/29/75 | 0.6 ± 0.2(3) | <0.2 | <0.2 | 0.10 ± 0.05 | NA | NA |
| | 8/27/75 | 0.7 ± 0.1(3) | <0.2 | <0.2 | 0.07 ± 0.01 | NA | NA |
| 43 | 10/7/74 | 2.0 ± 0.1(3) | < 3 | < 3 | NA | 1.6 ± 0.1 | <0.7 |
| 43 | 4/29/75 | <0.2(3) | <0.2 | <0.2 | 0.09 ± 0.04 | NA | NA |
| 43 | 8/26/75 | <0.2(3) | <0.2 | <0.2 | 0.03 ± 0.01 | NA | NA |
| 44 | 10/7/74 | <0.1(3) | < 3 | < 3 | 0.36 ± 0.04 | NA | NA |
| 44 | 8/26/75 | <0.2(3) | <0.2 | <0.2 | 0.020 ± 0.005 | NA | NA |

* No gamma-ray emitters were detected; typical detection limits are given for $^{60}Co$ and $^{137}Cs$.

** Pu concentration in well at Location 41 was < 0.005 pCi/1 $^{238}Pu$ and $^{239}Pu$ on 4/29/75.

Notes:

1. NA - not analyzed.
2. ± values are 2σ uncertainties based on counting error.
3. Exponents of 10 are indicated by numbers in parentheses; 1.1 ± 0.2(3) = (1.1 ± 0.2) x $10^{3}$.

concentrations to be less than 0.9 pCi/l. These radium concentrations are consistent with ambient levels expected in well waters from this area.(8)

Considering that Location 41 is near a drainage pathway south of the site and the low-level plutonium contamination of sediment in this wash, a well water sample from Location 41 was collected on April 29, 1975, but showed no detectable plutonium contamination (<0.005 pCi/l of $^{238}$Pu and $^{239}$Pu).

Low-level $^{3}$H contamination of nearby domestic wells has resulted from operations at the Maxey Flats burial site. A whole body dose of 0.1 mrem/yr was estimated for an adult receiving his drinking water from the well with the highest average $^{3}$H concentration, at Location 41, based on three measurements during the study. The dose rate was calculated for a daily intake of one liter of water with an average concentration of 1700 pCi/l, using a daily intake dose rate conversion factor of $6.2 \times 10^{-5}$ (mrem/yr)/(pCi/day). The dose conversion factor for $^{3}$H is based on the INDOS Program,(23) which uses the parameters given in Publication 10 of the International Commission on Radiological Protection and is described in Appendix 8.(24) The estimated dose of 0.1 mrem/yr corresponds to 0.06 percent of the recommended maximum dose of 170 mrem/yr to population groups from sources other than medical exposures.(25)

### 3.4 Radionuclides in Foods

Potential pathways of radionuclides from the waste burial site to man through various food chains were investigated. Studies were limited to the most probable pathways based on the radionuclides detected in surface water and evaporator effluents and the types of food produced near the site.

3.4.1 Radionuclides in milk. Milk was one of the primary food products sampled because of the potential exposure of individuals via the cow-milk-man pathway. Contamination of cattle forage and water could result primarily from deposition of radionuclides from the evaporator plume and the discharge of radioactive liquid effluents from the site via surface water.

Results of the radiochemical analyses of milk collected during this study are given in Table 3.7. The reported $^{3}$H concentrations are those associated with the water fraction of milk. Organically-bound $^{3}$H was not determined since only 5 to 10 percent is expected to be in this form.(26) The $^{3}$H concentration measured in the water fraction of the milk was converted to milk concentration using a factor of 90 percent, the percent by weight of water in milk.(27)

Milk samples were collected on June 3, 1975, from: a family cow grazing near the burial site entrance (Location 48), a commercial dairy herd grazing along Rock Lick Creek (Location

## Table 3.7

### Radionuclide Concentrations in Milk and Cows' Drinking Water, pCi/l

| Date | Location no. | $^{3}$H | $^{90}$Sr | $^{137}$Cs |
|---|---|---|---|---|
| | | **Milk** | | |
| 6/3/75 | 48 | 3.2 ± 0.2(3) | 7.3 ± 0.4 | 7 ± 2 |
| 6/3/75 | 46 | 1.0 ± 0.1(3) | 8.4 ± 0.4 | < 3 |
| 6/3/75 | 49 | 0.3 ± 0.1(3) | 4.4 ± 0.2 | < 3 |
| 6/10/75 | CIN* | < 0.2(3) | NA | NA |
| 8/27/75 | 41 | 6.5 ± 0.3(3) | 4.9 ± 0.3 | < 4 |
| 8/27/75 | 46 | 4.1 ± 0.3(3) | 2.0 ± 0.1 | < 4 |
| 8/28/75 | 47 | 1.3 ± 0.2(3) | 2.8 ± 0.4 | < 4 |
| 8/28/75 | 50 | 0.5 ± 0.2(3) | 2.3 ± 0.2 | < 4 |
| 9/3/75 | CIN* | < 0.3(3) | NA | NA |
| | | **Cows' Drinking Water** | | |
| 6/3/75 | 46 | 0.9 ± 0.2(3) | NA | NA |
| 6/3/75 | 48 | 3.6 ± 0.2(3) | NA | NA |
| 8/27/75 | 46 | 7.4 ± 0.2(3) | NA | NA |

*Milk sample from a commercial dairy in Cincinnati, Ohio.

Notes:

1. NA - not analyzed
2. ± values are 2σ uncertainties based on counting error.
3. Exponents of 10 are indicated by numbers in parentheses; 3.2 ± 0.2(3) = (3.2 ± 0.2) x $10^3$.

46), and a commercial dairy herd approximately 11 km west of the burial area (Location 49, not shown in Figure 3.3). Milk from a Cincinnati, Ohio, dairy was obtained as a $^{3}$H control sample on June 10, 1975. The $^{3}$H concentrations in milk from the three locations near the waste burial site were higher than in Cincinnati milk. The dairy at Location 49 was selected to serve as a control station since it was approximately 11 km west of the burial site, but the unexpected presence of $^{3}$H in milk from there, 300 pCi/l, may reflect a contribution from the site evaporator. Additional sampling at Location 49 and at more distant control locations, are necessary to determine the source of $^{3}$H detected at this location. The highest $^{3}$H concentration (3200 pCi/l) was measured in milk from a cow grazing at Location 48, which is a pasture located within the NECO site boundary, extending from the Maxey Flats Road to the site exclusion fence. The cow at Location 48 drinks from a small farm pond located in the pasture near the site entrance. A water sample from this pond was collected on June 3, 1975, for $^{3}$H analysis. Its concentration was 3600 pCi/l compared to 3200 pCi/l in the milk which suggests that the pond is the main source of $^{3}$H. The June 3 $^{3}$H concentration in milk from cows grazing at Location 46 and drinking from Rock Lick Creek was 1000 pCi/l compared to 900 pCi/l in water from the creek. Although the $^{3}$H concentration of milk collected on June 3 would reflect prior $^{3}$H intake by the cows, the similar $^{3}$H concentrations in milk and Rock Lick Creek water suggest that the creek is the main source of $^{3}$H observed in milk at Location 46.

Although $^{90}$Sr was detected in milk from Locations 46, 48 and 49, the concentrations are within the range expected from atmospheric fallout.(28) Likewise, the $^{137}$Cs level in milk from Location 46, 7 pCi/l, cannot be differentiated from fallout $^{137}$Cs.

Additional milk samples were collected during August 27-28, 1975. With the exception of Location 46, the sampling locations were different than those sampled on June 3, 1975. The new locations included: Location 41 - family cow grazing on pasture approximately 0.7 km south of the site and drinking from Rock Lick Creek; Location 47 - commercial dairy farm located approximately 3.1 km south-southwest of the site where cows drink water from Fox Creek; and Location 50 - commercial dairy farm located approximately 3.1 km south-southeast of the site where cows drink water from farm ponds.

The radionuclide concentrations of milk collected during August 27-28, 1975, are given in Table 3.7. Tritium was the only radionuclide detected in these samples that can be attributed to site operations. Concentrations were substantially higher at Locations 41 and 46 than at the other locations. Cows grazing at these locations drink from Rock Lick Creek, which had a $^{3}$H concentration of 7400 pCi on August 27, 1975. The elevated $^{3}$H levels in Rock Lick Creek and milk from Locations 41 and 46 on that date compared to June 3, 1975, resulted from the planned discharge of $^3H$ contaminated water from an on-site pond to Rock Lick Creek via the Main East Wash as recommended by the Nuclear Regulatory Commission.(16) The pond water, discharged intermittently during the latter part of July and first part of August, 1975, contained 45,000 pCi/l of $^3H$ according to analyses by NECO.(11)

The $^3H$ concentration in milk from Location 47 was 1300 pCi/l. Since cows at this location drink from Fox Creek both upstream and downstream from the confluence of Rock Lick Creek and Fox Creek, the source of $^3H$ could not be determined. The $^3H$ concentration in milk from Location 47 was lower than milk from Locations 41 and 46, which may reflect the lower $^3H$ concentration in Fox Creek.

The $^3H$ concentration in milk from Location 49 was 300 pCi/l compared to less than 200 pCi/l in Cincinnati milk. Although $^3H$ from the site evaporator is the only known source at this particular location, the concentration was so low that additional measurements would be necessary to verify the actual source.

3.4.2 Radionuclides in vegetables. An additional pathway for exposure of individuals living near the waste burial site is consumption of food products from family gardens. The site evaporator is the primary source of radioactivity for gardens at residences north of the site. Radionuclides from evaporator effluents and surface run-off could contribute radioactivity in vegetables from gardens located near the site drainage pathways. Primary emphasis was placed on sampling gardens located near the site evaporator (within 1.5 km) where potential contamination from evaporator effluents is greatest.

Vegetable samples were collected from five off-site gardens at local residences corresponding to Locations 40, 41, 44, 51 and 52 (see Figure 3.3). Their distances from the evaporator stack ranged from 0.5 km (Location 40) to 2.2 km (Location 44). Samples were also collected from gardens within the site boundary at Locations 48 and 53. The garden at Location 48 was maintained by a family living at that location, while the garden at Location 53 was located only a few meters from the NECO office (outside exclusion fence) and maintained by a NECO employee.

Vegetable samples were collected during the period of August 26-28, 1975. Gardens were sampled near the end of the growing season and were generally in poor condition due to drought. Many of the plants were wilted since gardens are not irrigated, and many vegetables commonly grown were not available. Tomatoes were available at all sampling locations and were generally edible, but most families had discontinued harvesting them. Other food products sampled included watermelons, sweet corn, grapes and cucumbers; however, corn and watermelons were not being harvested for consumption at this time.

The radionuclide concentrations in vegetable samples are given in Table 3.8. Concentrations are reported in pCi/kg (fresh weight) and, for $^3H$, pCi/l (tissue water). Tritium assay was limited to that associated with tissue water. Organically-bound $^3H$ was not measured since its contribution to the total $^3H$ concentration was estimated to be small.(26) The water content of the vegetable samples was determined during the azeotropic distillation separation procedure (see Appendix 7). The samples were distilled until all the tissue water was removed and the volume of water recovered was determined per gram of wet tissue. The measured $^3H$ concentration in tissue water in pCi/l was multiplied by the volume of tissue water per kg wet tissue (liters/kg) to give pCi per kg wet weight. The percentage by weight of water in vegetable samples varied from 57 for corn to 92 for tomatoes.

Ambient $^3H$ levels in vegetation at the time of sampling were below the detection limit of 250 pCi/kg, as determined by an analysis of tomatoes from the Cincinnati area. Tritium levels in precipitation during August 1975 in most areas of the U.S. were less than 200 pCi/l.(28)

The $^3H$ concentrations in garden products from off-site locations were all higher than 250 pCi/kg, ranging from 990 to 4620 pCi/kg. Higher $^3H$ concentrations were observed in vegetables from gardens located within the site boundary (Locations 48 and 53), ranging from 3570 to 78,700 pCi/kg. The elevated levels in vegetables from off-site gardens at Locations 51, 52 and 54 and the on-site gardens at Locations 48 and 53 can be attributed to $^3H$ releases from the evaporator. Although the evaporator is the most likely source of contamination of vegetables from Locations 40 and 41, contributions from surface run-off cannot be excluded.

Substantial differences in $^3H$ concentrations in the tissue water were observed for different types of vegetables from the same locations. For example, at Location 53 the concentration in cucumbers was 95,100 pCi/l of tissue water compared to 38,300 pCi/l of tissue water in tomatoes. These differences are proably related to the transpiration rates of the plants which differ for various types of vegetation depending on the growing cycle. Tritium levels in vegetables may vary considerably during the growing season depending on: 1) tritium concentrations in air which are related to its release rate from the evaporator and meteorological conditions; 2) rain frequency which affects deposition of tritiated water from the evaporator plume; and 3) biological and climatic conditions affecting water uptake by vegetation from soil and air. Routine sampling and analyses of garden products during the growing season would be necessary to determine the extent of $^3H$ contamination of vegetables from the evaporator.

## Table 3.8

### Radionuclide Concentrations in Garden Products From the Maxey Flats Area

| Sampling date | Location no. | Sample type | $^3H$ pCi/l (tissue water) | $^3H$ pCi/kg (fresh weight) | $^{90}Sr$ pCi/kg (fresh weight) | Gamma-ray emitters pCi/kg (fresh weight) |
|---|---|---|---|---|---|---|
| 8/27/75 | 40 | tomatoes | 5.4 ± 0.1 (3) | 4.6 ± 0.1 (3) | 2.4 ± 0.3 | ND |
| 8/27/75 | 41 | tomatoes | 4.7 ± 0.1 (3) | 4.0 ± 0.1 (3) | 2.6 ± 0.3 | ND |
| 8/27/75 | 41 | watermelon | 1.9 ± 0.2 (3) | 1.5 ± 0.1 (3) |  | ND |
| 8/27/75 | 44 | tomatoes | 1.1 ± 0.2 (3) | 1.0 ± 0.1 (3) | 2.1 ± 0.3 | ND |
| 8/26/75 | 51 | tomatoes | 1.9 ± 0.1 (3) | 1.8 ± 0.1 (3) | 0.8 ± 0.4 | ND |
| 8/26/75 | 51 | grapes | 5.2 ± 0.2 (3) | 3.9 ± 0.2 (3) |  | ND |
| 8/27/75 | 52 | tomatoes | 5.0 ± 0.1 (3) | 4.3 ± 0.1 (3) |  | ND |
| 8/26/75 | 48 | tomatoes | 6.2 ± 0.2 (3) | 5.3 ± 0.1 (3) |  | ND |
| 8/26/75 | 48 | corn | 6.3 ± 0.2 (3) | 3.6 ± 0.1 (3) |  | ND |
| 8/27/75 | 53 | tomatoes | 3.83 ± 0.03 (4) | 3.19 ± 0.02 (4) |  | ND |
| 8/27/75 | 53 | cucumbers | 9.51 ± 0.05 (4) | 7.87 ± 0.04 (4) |  | ND |

Notes:

1. ND - not detected; typical detection limits were: $^{60}Co$ - 8 pCi/kg, $^{137}Cs$ - 8 pCi/kg.
2. ± values are $2\sigma$ uncertainties as based on counting error.
3. Exponents of 10 are indicated by numbers in parentheses.

The concentration of gamma-ray-emitting radionuclides in garden products was below the detection limit for all samples. Typical detection limits were approximately 8 pCi/kg for $^{60}$Co and $^{137}$Cs.

Selected garden samples were analyzed for $^{90}$Sr. Its concentration in tomatoes from Locations 40, 41, 44, 51 and 53 ranged from 0.8 to 2.6 pCi/kg fresh weight. Since these concentrations were not significantly different from those at more distant locations, the probable source of $^{90}$Sr is atmospheric fallout.

With the exception of low-level $^{3}$H contamination, radionuclide levels in garden produce grown near the waste burial site were below detection limits or indistinguishable from atmospheric fallout. The consumption of produce from these gardens at the measured $^{3}$H concentrations would lead to rather low doses. The potential dose is probably the highest for tomatoes and cucumbers, since they have a high water content and are generally available for two to three months during the summer. To illustrate its magnitude, the annual dose was estimated for a hypothetical individual consuming tomatoes from off-site gardens with the highest measured $^{3}$H concentration. The dose to an adult individual was calculated as follows:

1. An annual intake was acquired by consuming daily 100 g of fresh tomatoes containing 4,600 pCi/kg of $^{3}$H for 90 days.

2. The annual intake was converted to an average daily intake and an annual dose was calculated using the dose rate-daily intake conversion factor of $6.2 \times 10^{-5}$ (mrem/yr)/(pCi/day) (see Appendix 8).

The estimated whole body dose based on the above calculation was 0.007 mrem/year for an adult.

Although the radiation dose to individuals living near the waste burial site from contaminated garden produce is quite low, the routine environmental surveillance program should include sampling and analyses of garden products for assessing exposures via this pathway.

# 4. E-SERIES TEST WELL MEASUREMENTS

## 4.1 General

As part of the Maxey Flats radiological monitoring program, KDHR and NECO routinely sample and analyze water samples from 12 test wells surrounding the burial site (designated as E-series test wells). The wells were constructed for NECO in 1973 under the supervision of Emcon Associates to obtain hydrological and geological information. The wells also provide a means of sampling ground water to detect potential subsurface migration of radioactivity from the trenches. Their location and depths are shown in Figure 4.1.

Since the KDHR program includes twice-monthly monitoring of radioactivity in the test wells, including $^{3}H$ and gross alpha- and beta-particle measurements, our efforts were directed in support of the KDHR program, including an interlaboratory $^{3}H$ cross check program with KDHR, NECO, and this laboratory. When the study was initiated only limited data were available regarding the specific radionuclide composition of well samples. During the KDHR "Six Months Study" analyses were expanded to include measurements of gamma-ray-emitting radionuclides, $^{89}Sr$, and $^{90}Sr$ in samples from wells 3E, 11E, 12E and 13E.(8) Plutonium concentrations were only measured in the suspended solids (primarily sediment) from wells 3E, 6E and 11E.(8)

Test wells were sampled during this study to identify and measure specific radionuclides not analyzed previously. In addition, emphasis was placed on determining the concentration of plutonium isotopes in the test wells and their distribution between sediment and water.

## 4.2 Sample Collection and Analyses

Test well water was sampled during site visits on October 8, 1974, and April 28, 1975. A sample from well 2E was collected by KDHR on April 28, 1975, and forwarded to this laboratory for analysis. Water samples were collected with a bailer supplied by NECO. The bailer consisted of a steel pipe, 90 cm long by 3.8 cm in diameter, with a foot valve which opens when the bailer strikes the bottom of the well. Since the top of the bailer is open, it fills also from the top when the water level exceeds 90 cm. Water samples generally had a high sediment load due to suspension of bottom sediment when the bailer was inserted.

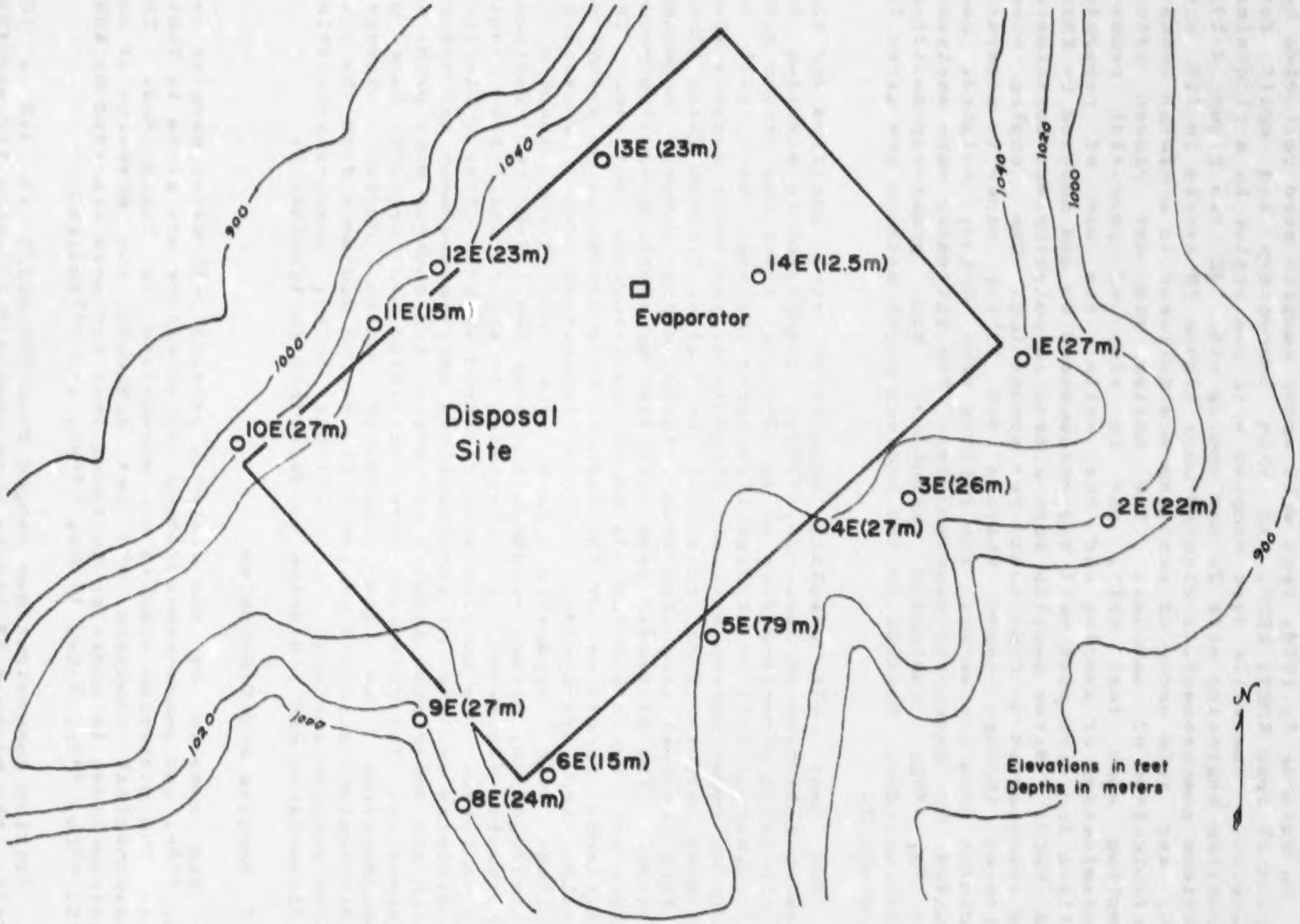

Figure 4.1 Test Well Locations and Depths

On October 8, 1974, test well water samples were collected by personnel from KDHR, NECO, and this laboratory and split for analyses. The wells were sampled with one bailer in a clockwise direction beginning with 2E and ending with 14E (see Figure 4.1). Previous measurements indicated much higher $^3H$ levels in 11E and 13E, and this order of sampling was followed to minimize cross-contamination of samples. The bailer was not rinsed after sampling each test well, and in view of potential cross-contamination of samples and the wells, the use of separate bailers for each test well was recommended to and adopted by KDHR and NECO. Water samples were stored in polyethylene containers and transported to Cincinnati for processing. The samples were filtered through tared Whatman #40 filter paper to separate sediment from the water. The filters were dried, weighed, and counted by gamma-ray spectrometry. The filtrates were analyzed for $^3H$, $^{90}Sr$ (selected samples), and gamma-ray-emitting radionuclides. Details of the radiochemical methods are given in Appendix 7.

The test well sampling procedures were modified for the samples collected on April 28, 1975. In addition to sampling in a clockwise direction from 1E to 13E, the bailer was rinsed with approximately 1-liter of distilled water between each well to minimize cross-contamination. Aliquots of the water samples were filtered within five hours of collection through glass fiber filters (nominal pore size 3-μm) followed by 0.45-μm membrane filters. The filtrates were acidified by addition of 10 percent nitric acid by volume and stored in polyethylene bottles. The unfiltered fractions of the samples were stored in polyethylene bottles and transported to our laboratory for processing. Sediment was separated from the unfiltered samples by centrifugation, dried, weighed, and combined with the sediment previously separated by filtration to afford sufficient sample for analysis. The samples were filtered shortly after collection to minimize exchange of radionuclides between sediment and water, which may occur when samples are stored for several days prior to separation. The filtrates were acidified to prevent loss of radionuclides on the container walls during storage. Radiochemical analyses of the filtrate and sediment from the well water samples included $^3H$ (filtrate only), gamma-ray-emitting radionuclides and plutonium as described in Appendix 7.

## 4.3 Results and Discussion

The results of the analyses of test well water samples for $^3H$, $^{90}Sr$, and gamma-ray-emitting radionuclides are given in Table 4.1. The plutonium results are summarized in Table 4.2. The radiochemical analyses did not indicate the presence of any radionuclides in addition to those that had been reported by KDHR ($^3H$, $^{60}Co$, $^{89}Sr$, $^{90}Sr$, $^{137}Cs$, $^{238}Pu$, and $^{239}Pu$).(8)

Tritium concentrations ranged from 200 pCi/l to $4.3 \times 10^6$ pCi/l. The highest $^3H$ levels were observed in wells 11E and 13E,

Table 4.1

Radionuclide Concentrations in Test Well Samples From Maxey Flats

| | | Filtrate, pCi/l | | | | Sediment, pCi/g (Dry Weight) | | | |
|---|---|---|---|---|---|---|---|---|---|
| Number | Sampled | $^{3}$H | $^{60}$Co | $^{90}$Sr | $^{137}$Cs | Grams/l | $^{60}$Co | $^{137}$Cs | $^{226}$Ra |
| 1E | 4/28/75 | 2.6 ± 0.2 (3) | NA | NA | NA | NA | | | |
| 2E | 10/8/74 | 3.1 ± 0.2 (3) | < 3 | 6.7 ± 0.2 | < 3 | NA | | | |
| 3E | 10/8/74 | 0.4 ± 0.2 (3) | < 18 | 3.3 ± 0.9 | < 20 | 10 | < 1.6 | < 1.6 | < 40 |
| 3E | 4/28/75 | 0.9 ± 0.2 (3) | NA | NA | NA | 73 | < 0.1 | < 0.1 | 12 ± 3 |
| 5E | 10/8/74 | 0.8 ± 0.1 (3) | < 4 | 1.6 ± 0.2 | < 4 | NA | | | |
| 6E | 10/8/74 | 2.5 ± 0.2 (3) | < 17 | 20 ± 2 | < 16 | 41 | < 0.3 | < 0.3 | < 10 |
| 6E | 4/28/75 | 12.5 ± 0.2 (3) | NA | NA | NA | 79 | < 0.1 | < 0.1 | 3 ± 1 |
| 8E | 10/8/74 | 0.8 ± 0.1 (3) | < 4 | NA | < 4 | NA | | | |
| 8E | 4/28/75 | 0.3 ± 0.1 (3) | < 14 | NA | < 14 | 3.8 | 2.5 ± 0.2 | 1.4 ± 0.2 | 10 ± 2 |
| 10E | 4/28/75 | 0.7 ± 0.2 (3) | < 12 | NA | < 12 | 6.1 | 0.22 ± 0.05 | < 0.4 | 34 ± 10 |
| 11E | 10/8/74 | 1.20 ± 0.05 (6) | 49 ± 6 | 16 ± 3 | < 15 | 73 | 0.6 ± 0.2 | < 0.3 | 5 ± 2 |
| 11E | 4/28/75 | 3.48 ± 0.01 (6) | 50 ± 20 | NA | < 17 | 19.3 | 1.2 ± 0.2 | < 0.1 | 3 ± 1 |
| 12E | 10/8/74 | 3.5 ± 0.2 (3) | < 1.8 | 1.9 ± 0.5 | < 1.6 | NA | | | |
| 12E | 4/28/75 | 11.9 ± 0.2 (3) | < 14 | NA | < 14 | 1.2 | 19 ± 1 | 1.6 ± 0.5 | < 12 |
| 13E | 10/8/74 | 2.8 ± 0.1 (6) | 11 ± 3 | 6.1 ± 0.2 | < 2.1 | NA | | | |
| 13E | 4/28/75 | 4.33 ± 0.01 (6) | < 16 | NA | < 16 | 4.2 | 2.7 ± 0.3 | 1.9 ± 0.2 | < 31 |
| 14E | 10/8/74 | 2.4 ± 0.2 (3) | < 3 | 3.0 ± 0.4 | < 3 | NA | | | |

Notes:

1. Exponents of 10 are indicated by numbers in parentheses.
2. ± values are uncertainties based on 2σ counting error.
3. NA - not analyzed.

Table 4.2

Plutonium Concentrations in Test Well Samples

| Well number | Date sampled | Solids, grams/l | Sediment, pCi/g | | Filtrate, pCi/g | |
|---|---|---|---|---|---|---|
| | | | $^{238}$Pu | $^{239}$Pu | $^{238}$Pu | $^{239}$Pu |
| 1E | 4/28/75 | 2.6 | 2.9 ± 0.2 | 0.08 ± 0.03 | NA | NA |
| 2E | 9/11/75 | 0.4 | 11.7 ± 0.5 | 0.27 ± 0.05 | < 0.02 | < 0.01 |
| 3E | 4/28/75 | 73 | 0.56 ± 0.05 | 0.015 ± 0.007 | < 0.07 | < 0.03 |
| 6E | 4/28/75 | 79 | 0.08 ± 0.02 | < 0.005 | NA | NA |
| 8E | 4/28/75 | 3.8 | 16 ± 1 | 0.50 ± 0.05 | < 0.02 | < 0.02 |
| 10E | 4/28/75 | 6.1 | 3.7 ± 0.3 | < 0.05 | < 0.1 | < 0.1 |
| 11E | 4/28/75 | 19.3 | 0.39 ± 0.04 | 0.015 ± 0.006 | < 0.1 | < 0.1 |
| 12E | 4/28/75 | 1.2 | 7.3 ± 0.5 | 0.29 ± 0.05 | < 0.05 | < 0.05 |
| 13E | 4/28/75 | 4.2 | 7.5 ± 0.5 | 0.34 ± 0.05 | NA | NA |

Notes:

1. NA - not analyzed
2. ± values are uncertainties based on 2σ counting error.
3. Sample 2E was collected by KDHR and acidified to 10% in $HNO_3$.

and were significantly higher than the concentrations in the other test wells. The lowest $^{3}H$ concentration measured in well 11E or 13E was approximately two orders of magnitude higher than the highest concentration in any of the other test wells. These results support the conclusion of the NRC Review Group that the high $^{3}H$ levels in wells 11E and 13E have resulted from subsurface migration of $^{3}H$ from trenches 31 and 33-L.(16) The most probable source of $^{3}H$ contamination in wells 1E, 2E, 3E, 5E, 6E, 8E, 10E, 12E and 14E is also subsurface migration; however, the $^{3}H$ levels are low and some contribution from infiltration of contaminated surface water cannot be excluded. A probable source of contaminated surface water is $^{3}H$ from the site evaporator. Measurements of the $^{3}H$ levels in precipitation at the test well locations would be valuable in estimating the potential contribution from infiltration of contaminated surface water.

Gamma-ray-emitting radionuclides detected in test wells included $^{60}Co$, $^{137}Cs$ and $^{226}Ra$. The highest $^{60}Co$ concentrations were associated with test wells 11E (50 pCi/l of filtrate), 13E (11 pCi/l of filtrate) and 12E (19 pCi/g of suspended material). Although $^{137}Cs$ was detected in sediment from wells 2E, 3E, 5E, 12E, and 13E, the concentrations were quite low, ranging from 1.4 to 1.9 pCi/g. Radium-226 concentrations in sediment showed considerable variation, ranging from 3 to 34 pCi/g. Although appropriate control samples were not available for comparison, this range probably reflects the differences in naturally-occurring $^{226}Ra$ concentrations in the various geological formations rather than contributions from waste buried at the site.

Strontium-90 analyses were limited to the filtrate fraction of test wells 2E, 3E, 5E, 6E, 11E, 12E, 13E, and 14E. Concentrations ranged from 1.6 to 20 pCi/l. In view of the elevated levels in the test wells, $^{90}Sr$ analyses should be included in the routine test well monitoring program.

The concentration of plutonium isotopes in sediment from the test wells ranged from 0.08 to 16 pCi/g for $^{238}Pu$ and from <0.005 to 0.5 pCi/g for $^{239}Pu$. The $^{238}Pu$ concentrations in test well sediments ranged from approximately 200 to 40,000 times current levels of $^{238}Pu$ in soils in the U.S. from atmospheric fallout ($4 \times 10^{-4}$ pCi/g $^{238}Pu$).(29) These analyses showed plutonium contamination in all test well sediment samples, and confirmed the results for test wells 3E, 6E ($^{238}Pu$ only) and 11E reported by KDHR; however, the concentrations were substantially lower than previously observed by KDHR.(2,8) The plutonium concentration in test wells from the KDHR "Six-Months Study" are compared in Table 4.3 with samples collected later during this study. Although the plutonium concentrations appear to have decreased from the levels observed during the "Six-Months Study" in 1974, additional data are needed for verification.

## Table 4.3

### Comparison of Plutonium Concentrations in Test Well Sediments

| | KDHR Study(8) | | EPA | |
|---|---|---|---|---|
| Test well | $^{238}$Pu (pCi/g) | $^{239}$Pu (pCi/g) | $^{238}$Pu (pCi/g) | $^{239}$Pu (pCi/g) |
| 3E | 3.9 ± 0.3 | 0.05 ± 0.01 | 0.56 ± 0.05 | 0.015 ± 0.007 |
| 6E | 2.7 ± 0.3 | 0.09 ± 0.02 | 0.08 ± 0.02 | < 0.005 |
| 6E | 3.4 ± 0.2 | 0.10 ± 0.01 | | |
| 11E | 9.9 ± 0.9 | 0.21 ± 0.03 | 0.39 ± 0.04 | 0.015 ± 0.006 |
| 11E | 15 ± 1 | 0.26 ± 0.03 | | |

Notes:

1. ± values are $2\sigma$ uncertainties based on counting error.
2. KDHR samples collected between 2/18/74 and 5/18/74; EPA samples collected on 4/28/75.

The concentration of plutonium isotopes in the water fraction (filtrate) from the test wells was below detectable levels in all samples; the detection limit varied from 0.04 to 0.3 pCi/l for $^{238}Pu$ and $^{239}Pu$, depending on the volume of water available for analysis. The absence of detectable levels of plutonium in the water suggests that it is primarily associated with insoluble species (> 0.45-μm particles) rather than soluble species. It has been suggested that complexing agents in the trenches at Maxey Flats could produce soluble plutonium species which could lead to subsurface migration through the rock formations from the trenches to the test wells.(2) The low plutonium concentrations in the water, however, do not support this hypothesis as a probable mechanism for subsurface migration of plutonium. However, information on complex-ion formation of plutonium in trench leachate would be useful. These data do not exclude the possible transport of plutonium through the rock zone on fine (> 0.45 μm) particles.

## 4.4 Signficance of Test Well Measurements

Although the measurements show that disposal operations at Maxey Flats have resulted in low-level contamination of the test wells, the data are not sufficient to establish subsurface migration from the trenches as the only source, or to evaluate the extent of subsurface migration from the trenches. Possible sources of test well contamination have been attributed to the introduction of contaminated soil from the surface and the use of contaminated water during drilling, and surface run-off entering the well at the casing-soil interface. The possibility of some cross-contamination of the wells during sampling cannot be excluded; however, this would not be expected to be a major source of contamination.

With the exception of the high tritium levels in test wells 11E and 13E, the radionuclide levels were quite low, indicating that subsurface migration of radionuclides other than $^{3}H$ has not been extensive compared to the quantities of radioactivity buried at the site and the radionuclide concentrations in the trench water.(5,19) Many of the potential problems associated with subsurface migration may be alleviated by the improved waste management practices initiated within the last three years. However, additional radiological, hydrological and geological investigations would be necessary to determine if the improved water management program (e.g., minimizing the infiltration of surface water into the trenches and pumping the trenches) will be effective in controlling subsurface migration to the environment. Detailed recommendations (at the request of KDHR) for additional studies have been made by an Environmental Study Design Committee composed of scientists from various Kentucky state and federal agencies.(30)

Routine monitoring of the test wells should be continued to determine if radionuclide levels are increasing or decreasing.

These data, along with additional hydrological and geological information, will be valuable in evaluating the extent of subsurface migration of radioactivity. It should be pointed out that NECO has implemented an improved test well monitoring program including some specific radionuclide analyses. However, recent test well data collected by NECO have not been received for review in this report. Specific recommendations regarding the test well monitoring program are given in Section 5.

The potential implications of plutonium transport from the site by various pathways provide an important part of the selection and regulation of low-level radioactive waste disposal sites and, as such, suggest the need for additional hydrological, geological and radiological studies.

## 5. REVIEW OF ENVIRONMENTAL AND TEST WELL MONITORING PROGRAMS

The NECO routine environmental and test well monitoring programs are summarized below:

| Exposure pathway or sampling media | No. of sampling locations | Sampling frequency | Type of analysis |
|---|---|---|---|
| Test well water | 10 | twice-monthly | $^3$H, gross alpha and beta |
| Surface water | 21 | twice-monthly | $^3$H, gross alpha and beta |
| Domestic wells (drinking water) | 5 | twice-monthly | $^3$H, gross alpha and beta |
| Air (fenceline) | 8 | continuous (weekly analysis) | $^3$H, gross alpha and beta |
| Air (limiting residence) | 1 | continuous (weekly analysis) | $^3$H, gross alpha and beta |
| Direct radiation (fenceline) | 9 | continuous (quarterly analysis) | TLD (gamma-ray exposure) |

In addition to gross radioactivity measurements, specific isotopic analyses are made when gross alpha or beta radioactivities exceed control values.

Routine environmental monitoring by KDHR is limited to twice-monthly sampling and analyses of surface water and domestic wells for $^3$H and gross alpha- and beta-particle radioactivity.

Although the analyses of test well samples for $^3$H and gross alpha- and beta-particle radioactivity have been useful for detecting elevated levels of radioactivity in ground water, this monitoring program should include analyses for individual radionuclides. To ensure reliable and more useful data regarding subsurface migration of radioactivity from the trenches, specific recommendations for sampling and analyses of the test wells follow:

A. Analyses of test well water should measure radionuclides associated with both particulate (suspended solids) and dissolved material. Although somewhat arbitrary, dissolved material is defined as the material which passes through a filter of a specified pore size, generally a 0.45-μm membrane filter, and material retained by the filter is classified as particulate or suspended material. Separation of the two fractions at the time of collection is preferable to miminize changes in the distribution of radionuclides between particulate and dissolved species, but may be impractical when high particulate concentrations occur. If the dissolved fraction is to be stored for analysis, acidification is recommended to prevent or minimize losses from deposition on the container.

In addition to the radiochemical data, the concentration of the suspended material should be reported in g/liter. Radionuclide concentrations should be reported in appropriate units, e.g., pCi/liter - dissolved, pCi/g - suspended.

B. Specific radionuclide analyses of samples should include $^{3}H$ (dissolved only), $^{90}Sr$, gamma-ray-emitting radionuclides, $^{238}Pu$ and $^{239}Pu$. Since samples are collected twice-monthly and analyzed for $^{3}H$ and gross alpha- and beta-particle radioactivity, aliquots of dissolved and suspended material could be composited for quarterly radionuclide analyses. The need for more frequent radionuclide analyses would be indicated by results of $^{3}H$ and gross radioactivity measurements.

The current NECO environmental monitoring program is not adequate to satisfy the generally accepted objectives and requirements of environmental monitoring around nuclear installations.(31) Although the design of an environmental program is dependent on the nature of the installation, the contents of the effluents and the site, environmental monitoring, in general, should provide data to:

a. confirm or identify critical exposure pathways,

b. assess the radiation exposure to individuals or populations residing near the facility,

c. detect build-up of radioactivity in the environment and measure long-term trends in environmental radioactivity levels, and

d. establish correlations between environmental radioactivity levels and radioactivity discharged from the site.

The environmental monitoring program at Maxey Flats should be reviewed and restructured to meet these objectives. In addition to addressing the adequacy of the current program, guidelines should be established for an adequate analytical quality control or assurance program and the issuing of a semi-annual environmental report. Based on our investigations at the Maxey Flats burial site, measurements that would improve the environmental monitoring program are discussed below.

The design of an environmental monitoring program to meet the objectives outlined above is generally based on knowledge of the source term, including the types and quantities of radionuclides released to the environment, which is obtained by effluent monitoring. Since the discharge of radioactivity from the Maxey Flats site via aqueous pathways is not a controlled release situation, the environmental surveillance program should identify and measure radioactivity released by this route. The current surface water monitoring program provides limited information regarding the concentration and identity of radionuclides discharged to streams near the site, but is not designed to determine the quantity of radioactivity released.

Measurement of the radioactivity discharged from the site via the aqueous pathways would require continuous flow rate measurements and proportional sampling of the three main drainage pathways. Because construction of three sampling stations would involve considerable expense, an alternative would be a single station to monitor effluents after discharge to Rock Lick Creek. Since all the main drainage pathways empty into this Creek, a sampling station in Rock Lick Creek downstream from the outfall of Drip Springs Hollow would monitor discharges from the main effluent streams. A gauging station in Rock Lick Creek, maintained by the USGS, is located approximately 0.5 km downstream from the outfall of Drip Springs Hollow Creek and could be used in conjunction with a proportional sampler for monitoring discharges to Rock Lick Creek. An additional sampling station could be established in Rock Lick Creek upstream from the influence of the site drainage to differentiate between site-related radioactivity and "background" radioactivity in fallout from atmospheric nuclear tests and natural radioactivity. Since current levels of radioactivity from atmospheric nuclear tests are quite low, a continuous sampling station for background measurements may not be necessary if specific radionuclide analyses were made on samples collected at the effluent monitoring station.

Continuous monitoring of radioactivity discharged to Rock Lick Creek would provide additional guidance as to the significance of the radioactivity leaving the site and the need for monitoring additional aquatic pathways, such as fish. Long-term measurements would also establish if the discharge levels are decreasing as a result of improved waste management practices.

The analysis of stream bed sediment would be useful in detecting the build-up of radioactivity in the environment from aqueous discharges. However, since contaminated stream bed sediment is not presently an important exposure pathway, annual or semi-annual sampling would be sufficient.

In view of the elevated $^{3}H$ levels in milk from cows drinking from Rock Lick Creek, routine monitoring of radionuclides in milk should be initiated to assess the potential dose from this pathway. Radionuclide analyses of milk should include $^{3}H$ and $^{90}Sr$; analyses for additional radionuclides would be dictated by the results of effluent monitoring in Rock Lick Creek.

Since the evaporator appears to be a major source of radioactivity at the burial site, air samples collected at the fenceline and particularly at the residence of the limiting receptor should be routinely composited quarterly and analyzed for gamma-ray-emitting radionuclides and for $^{3}H$, $^{90}Sr$, $^{238}Pu$ and $^{239}Pu$. This together with wind frequency data will provide average airborne concentrations of specific radionuclides to assist in estimating dose to man or to predict their contributions to other pathways.

Tritium was the only radionuclide detected in garden products that can be attributed to discharges from the site evaporator. Although the potential dose associated with consumption of $^{3}H$-contaminated vegetables was quite low, our measurements were limited and may not be representative of radionuclide concentrations during the growing season. Since the production of vegetables in this area is limited to small family gardens and collection of suitable quantities of vegetables may limit the frequency of sampling, measurements of radionuclide levels in other types of vegetation during this season should be included in the routine environmental monitoring program. Sampling of grass, for example, from specific plots may serve as a suitable indicator.

## 6. SUMMARY AND CONCLUSIONS

Information obtained during this study indicates that the quantities of radioactivity detected outside the burial trenches are so low that they do not appear to be a significant hazard to the environment or to public health in the Maxey Flats area, at the present time. However, the potential long-range impact of these contaminants is not known.

### 6.1 Evaporator Study

Fifteen long-lived radionuclides have been identified in stack effluent during evaporation of wastes from six storage tanks. Tritium, observed in every sample of stack discharge, was the predominant radionuclide. Cobalt-60, $^{90}$Sr and $^{137}$Cs were also found in every sample, and $^{22}$Na, $^{106}$Ru and $^{134}$Cs were detected frequently. Discharge rates of $^{3}$H ranged up to $1.9 \times 10^{3}$ μCi/s; the highest observed rate of other radionuclides was $2.1 \times 10^{-2}$ μCi/s ($^{137}$Cs).

Long-lived alpha-particle emitters in stack effluent included $^{226}$Ra, $^{238}$Pu and $^{239}$Pu. Americium-241 was observed in wastes being treated but levels in stack discharge, if present, were below detection levels. No extensive analyses have been conducted so far to identify all radionuclides of this type.

Sodium-22, $^{90}$Sr, $^{134}$Cs, $^{137}$Cs and $^{226}$Ra were associated with dissolved matter in stack effluent. Most $^{54}$Mn, $^{55}$Fe, $^{60}$Co, $^{125}$Sb, $^{228}$Ac and Pu were also in this form; $^{106}$Ru was insoluble. The solubility of $^{14}$C is uncertain--more analyses are needed to determine the extent of $^{14}$C in discharges.

Water used to dilute wastes for treatment was found to contain $^{3}$H, $^{60}$Co, $^{90}$Sr, $^{106}$Ru, $^{134}$Cs and $^{137}$Cs. Contamination of dilution water resulted either from storage tank leakage or depletion of the evaporator stack plume (e.g., by rainfall or condensed droplets) as it passed over the former tank berm area.

Tritium concentrations are reduced slightly in the waste treatment process due to water formed by combustion of evaporator fuel. Decontamination factors (DF's) for the entire treatment system were determined for $^{60}$Co, $^{90}$Sr, $^{106}$Ru, $^{134}$Cs, $^{238}$Pu and $^{239}$Pu. Observed DF's for $^{137}$Cs and plutonium were highly variable. Because of the variability of these measurements and the importance of plutonium, more tests are needed to obtain representative values.

Samples taken within the treatment system during stack measurements were highly variable and difficult to correlate with radionuclide concentrations in stack effluent. The radionuclide contents of batches previously treated appear to influence subsequent batch concentrations.

Annual average dose from exposure to six principal radionuclides in evaporator stack discharge were calculated for the limiting receptor, an occupant at the residence located NNE of the stack at a distance of 0.8 km. The calculations were based on the average radionuclide concentrations in all storage tanks measured in 1973, average DF's observed in this study, reported treatment system parameters, and available climatological data.

Most dose was contributed by airborne ground-level concentrations of $^{3}$H water vapor, estimated to be 2.6 mrem/year. The other radionuclides, $^{60}$Co, $^{90}$Sr, $^{137}$Cs, $^{238}$Pu and $^{239}$Pu, produced less than 0.1 mrem/year each; the dose calculations for $^{137}$Cs, $^{238}$Pu and $^{239}$Pu are tentative, however, pending more DF measurements.

## 6.2 Environmental Study

The principal radionuclides detected in off-site surface water samples were $^{3}$H and $^{90}$Sr. The highest $^{3}$H concentration was 179,000 pCi/l in water from a wash on the west side of the site, outside the exclusion area (i.e., unrestricted area). This corresponds to 6 percent of the maximum permissible concentration (MPC) for $^{3}$H in water discharged to unrestricted areas.(22) The highest $^{90}$Sr concentration was 80 pCi/l in the Main East Wash, corresponding to 27 percent of the MPC for $^{90}$Sr in water. The $^{3}$H and $^{90}$Sr levels in Rock Lick Creek were lower than in the primary drainage pathways; the highest concentrations were 4700 pCi/l and 5.8 pCi/l, respectively. The major aqueous pathways for radionuclides moving from the site were the Main East Wash and the wash on the west side of the site. The principal vehicle of transport appeared to be precipitation run-off from the surface of the burial site. Contamination of the site surface could have resulted from a number of sources, including lateral migration through the soil zone from the trenches to the land surface, spills during burial and trench pumping operations, and deposition from the evaporator plume. However, the relative contribution from these sources could not be determined. Deposition of radionuclides from the evaporator plume, especially $^{3}$H, could be a major source of radioactivity observed in surface water, but additional studies would be necessary to evaluate its significance.

Radionuclides detected in stream bed sediment included $^{54}$Mn, $^{60}$Co, $^{90}$Sr, $^{137}$Cs, $^{238}$Pu and $^{239}$Pu. The highest concentrations were in samples from the Main East Wash which is the major drainage pathway for the burial site. The sediment data supported the conclusion, based on surface water measurements, that the transport of radionuclides from the site surface by precipitation run-off was a major source of the radioactivity detected in the drainage pathways.

The radionuclide levels in sediment were quite low and of little significance relative to population exposure. The accumulation of radionuclides in sediment serves as a reservoir or source of radionuclides that can be released by desorption or resuspension of the sediment. Considering the measured concentrations, however, contaminated sediment did not represent a significant source compared to the levels of $^{3}H$ and $^{90}Sr$ measured in surface water.

Only $^{3}H$ was detected in domestic well water at concentrations which reflect contributions from site operations. The source of the contamination may be a combination of surface run-off from the site and deposition from the evaporator plume. A daily intake of one liter of well water with an average concentration of 1700 pCi/l, the highest average concentration measured, would result in a total-body dose of only 0.1 mrem/year.

Radiochemical analyses of milk samples showed that $^{3}H$ releases from the Maxey Flats burial site have produced low-level contamination of milk from cows located within 3.1 km of the site. The highest $^{3}H$ concentration was associated with milk from cows drinking from Rock Lick Creek and can be attributed to releases from the site to Rock Lick Creek. Elevated $^{3}H$ levels in milk from a cow grazing near the site entrance were attributed to site evaporator effluent.

The potential dose to an individual from drinking $^{3}H$ in milk at the concentrations (300-6,500 pCi/l) detected in samples near the Maxey Flats site is quite low. Daily consumption of one liter of milk containing 6,500 pCi/l of $^{3}H$ would lead to an annual total body dose of approximately 0.4 mrem. The average dose rate to consumers of local milk is probably less. A more accurate assessment of the dose from this pathway would require more extensive monitoring efforts than attempted in this study.

With the exception of low-level $^{3}H$, radionuclide levels in garden produce—tomatoes, watermelons, corn, grapes and cucumbers—grown near the waste burial site were below detection limits or indistinguishable from atmospheric fallout. Tritium concentrations in vegetables grown in off-site locations ranged from 990 to 4,620 pCi/kg. Higher $^{3}H$ concentrations, 3,570 to 78,700 pCi/kg, were measured in vegetables from gardens located on site property. The evaporator plume is the most likely source of this contamination, however, $^{3}H$ in surface water run-off may contribute at some garden locations. Differences in $^{3}H$ concentration of tissue water from vegetables grown in the same garden were attributed to the different transpiration rates of plants. The total body radiation dose to an individual consuming

100 g per day of tomatoes containing 4,600 pCi $^{3}H$/kg (the highest off-site $^{3}H$ concentration observed) during a 90-day season was estimated to be less than 0.01 mrem/year.

## 6.3 E-Series Test Well Measurements

Radionuclides measured in the E-series test well samples were $^{3}H$, $^{60}Co$, $^{90}Sr$, $^{137}Cs$, $^{226}Ra$, $^{238}Pu$ and $^{239}Pu$. However, only $^{3}H$, $^{60}Co$ and $^{90}Sr$ were observed to exist in the soluble fraction, and the presence of $^{226}Ra$ may not be related to wastes buried at the site. Within the limits of detection, all plutonium was associated with sediment, which raises the question regarding the mechanism of its movement from the trenches. Although subsurface migration is apparently the major pathway responsible for the presence of radionuclides in the wells, possible contamination during drilling or from contaminated surface water entering the wells at the casing-soil interface cannot be excluded. Even though subsurface transport might explain the occurrence of radionuclides in the test wells, their presence off-site--in the Main East Wash, No-Name Hollow Creek, Rock Lick Creek, etc.--appears to be primarily from surface water run-off and evaporator plume depletion. Additional geological, hydrological and radiological measurements would be necessary to evaluate the extent of subsurface migration of radionuclides from the trenches.

## 6.4 Recommendations for Future Studies

Recommendations for improvement of the present routine environmental and test well monitoring programs at the Maxey Flats burial site are discussed in Section 5. Major changes recommended are, briefly:

1) Install and operate a continuous water sampling station on Rock Lick Creek at the site of the USGS gauging station.

2) Include milk and vegetables, during the growing season, as routine sampling media to be analyzed for $^{3}H$.

3) Perform specific radionuclide analysis on both particulate and dissolved material in test well samples.

4) Sample stream bed sediment on a semi-annual or annual basis for radionuclide analysis to monitor build-up of radioactivity in the environment from the aqueous pathway.

5) Analyze quarterly composited air filters from fenceline and residential air samplers for radionuclides emitting gamma-rays and for $^{90}Sr$, $^{238}Pu$ and $^{239}Pu$.

Additional short-term studies planned at the Maxey Flats burial site and based on this study include:

1) Determine the distribution of plutonium between particulate and dissolved material in test well water samples, and the distribution of plutonium as a function of particle size.

2) Measure the plutonium concentration in vegetation and soil from the trench area.

3) Measure $^{3}H$ levels in environmental media, particularly vegetation, and determine the percent associated with water and that which is organically bound.

4) Measure radionuclide concentrations in air outside the fenceline to verify dose estimates from evaporator effluents, and determine the contribution of washout from the plume to surface water contamination.

5) Perform additional sampling of evaporator treatment plant to determine more accurately DF's for $^{137}Cs$ and plutonium and quantities of $^{14}C$ in stack discharge.

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## APPENDIX 1. SENSITIVITY LEVELS FOR ANALYSES OF EVAPORATOR EFFLUENT,* μCi/ml

| Radionuclide | Air filter | Water | Membrane filter |
|---|---|---|---|
| 12.3 -y $^{3}$H | --- | $3 \times 10^{-7}$ | --- |
| 5730 -y $^{14}$C | --- | $3 \times 10^{-8}$ | --- |
| 2.60 -y $^{22}$Na | $5 \times 10^{-13}$ | $1 \times 10^{-8}$ | $5 \times 10^{-9}$ |
| 313 -d $^{54}$Mn | $2 \times 10^{-12}$ | $1 \times 10^{-8}$ | $4 \times 10^{-9}$ |
| 2.7 -y $^{55}$Fe | $2 \times 10^{-11}$ | $3 \times 10^{-8}$ | $1 \times 10^{-8}$ |
| 5.26 -y $^{60}$Co | $2 \times 10^{-12}$ | $1 \times 10^{-8}$ | $1 \times 10^{-9}$ |
| 244 -d $^{65}$Zn | $2 \times 10^{-12}$ | $1 \times 10^{-8}$ | $1 \times 10^{-9}$ |
| 28.5 -d $^{90}$Sr | $1 \times 10^{-14}$ | $5 \times 10^{-9}$ | $1 \times 10^{-10}$ |
| 369 -d $^{106}$Ru | $1 \times 10^{-11}$ | $1 \times 10^{-7}$ | $4 \times 10^{-9}$ |
| 2.77 -y $^{125}$Sb | $2 \times 10^{-12}$ | $4 \times 10^{-8}$ | $2 \times 10^{-9}$ |
| 8.06 -d $^{131}$I | $1 \times 10^{-12}$ | $1 \times 10^{-8}$ | $1 \times 10^{-9}$ |
| 2.07 -y $^{134}$Cs | $1 \times 10^{-12}$ | $1 \times 10^{-8}$ | $1 \times 10^{-9}$ |
| 30.0 -y $^{137}$Cs | $1 \times 10^{-12}$ | $1 \times 10^{-8}$ | $1 \times 10^{-9}$ |
| 1600 -y $^{226}$Ra | $4 \times 10^{-12}$ | $1 \times 10^{-7}$ | $3 \times 10^{-9}$ |
| 6.13 -h $^{228}$Ac | $2 \times 10^{-12}$ | $2 \times 10^{-8}$ | $2 \times 10^{-9}$ |
| 87.7 -y $^{238}$Pu | $5 \times 10^{-14}$ | $4 \times 10^{-11}$ | $8 \times 10^{-12}$ |
| $2.4 \times 10^{4}$ -y $^{239}$Pu | $5 \times 10^{-14}$ | $4 \times 10^{-11}$ | $8 \times 10^{-12}$ |
| 433 -y $^{241}$Am | $1 \times 10^{-12}$ | $9 \times 10^{-8}$ | $2 \times 10^{-9}$ |
| Gross alpha | --- | $1 \times 10^{-9}$ | $5 \times 10^{-9}$ |

*Values calculated at the 99.7% (3σ) confidence level and based on typical sample volumes and counting intervals.

## APPENDIX 2. IN-PLANT SAMPLING DATA

| Stack test no. | In-plant sample no. | Date | Time | Location |
|---|---|---|---|---|
| 1 | 1 | Nov. 6, 1974 | 1325 | Evaporator |
| | 3 | " | 1345 | Settling Tank #1 |
| 2 | 6 | Nov. 6, 1974 | 1634 | Evaporator |
| | 8 | " | 1615 | Settling Tank #2 |
| 3 | 11 | Nov. 7, 1974 | 1012 | Evaporator |
| | 13 | " | 1018 | Settling Tank #2 |
| 4 | 16 | Nov. 7, 1974 | 1441 | Evaporator |
| | 18 | " | 1446 | Settling Tank #2 |
| | 20 | " | 1654 | Evaporator |
| | 22 | " | 1656 | Settling Tank #1 |
| 5 | 25 | Nov. 8, 1974 | 0955 | Evaporator |
| | 27 | " | 0955 | Settling Tank #2 |
| 6 | 30 | April 8, 1975 | 1418 | Settling Tank #1 |
| | 33 | " | 1525 | Settling Tank #1 |
| 7 | 34* | April 9, 1975 | 1000 | Evaporator |
| | 35 | " | 1003 | Settling Tank #2 |
| | 37 | " | 1050 | Evaporator |
| | 38 | " | 1052 | Settling Tank #1 |
| 8 | 40 | April 9, 1975 | 1349 | Evaporator |
| | 41 | " | 1353 | Settling Tank #2 |
| | 43 | " | 1550 | Evaporator |
| | 44 | " | 1552 | Settling Tank #1 |
| 9 | 46 | April 10, 1975 | 1003 | Evaporator |
| | 47 | " | 1006 | Settling Tank #1 |
| | 49 | " | 1133 | Evaporator |
| | 50 | " | 1135 | Settling Tank #1 |
| 10 | 52 | May 20, 1975 | 1412 | Evaporator |
| | 53 | " | 1416 | Settling Tank #1 |
| | 54 | " | 1437 | Settling Tank #2 |
| 11 | 55 | May 21, 1975 | 0940 | Evaporator |
| | 56 | " | 0943 | Settling Tank #2 |
| | 57 | " | 1105 | Evaporator |
| | 58 | " | 1107 | Settling Tank #2 |
| | 59 | " | 1111 | Settling Tank #1 |
| 12 | 60 | May 21, 1975 | 1336 | Evaporator |
| | 61 | " | 1338 | Settling Tank #1 |
| | 62 | " | 1513 | Evaporator |
| | 63 | " | 1515 | Settling Tank #2 |
| 13 | 64 | May 22, 1975 | 0953 | Evaporator |
| | 65 | " | 0955 | Settling Tank #1 |
| | 66 | " | 1119 | Evaporator |
| | 67 | " | 1121 | Settling Tank #1 |
| 14 | 68 | Sept. 29, 1975 | 1353 | Evaporator |
| | 69 | " | 1355 | Settling Tank #2 |
| | 70 | " | 1519 | Evaporator |
| | 71 | " | 1520 | Settling Tank #2 |
| 15 | 72 | Sept. 30, 1975 | 0939 | Evaporator |
| | 73 | " | 0941 | Settling Tank #2 |
| | 74 | " | 1106 | Evaporator |
| | 75 | " | 1107 | Settling Tank #2 |
| | 76** | " | 1145 | Settling Tank #1 |
| | 77** | " | 1230 | Settling Tank #1 |
| 16 | 78 | Sept. 30, 1975 | 1313 | Evaporator |
| | 79 | " | 1315 | Settling Tank #2 |
| | 80** | " | 1424 | Settling Tank #1 |
| | 81** | " | 1450 | Settling Tank #1 |
| | 82 | " | 1459 | Evaporator |
| | 83 | " | 1501 | Settling Tank #2 |
| 17 | 84 | Oct. 1, 1975 | 1031 | Evaporator |
| | 85 | " | 1033 | Settling Tank #2 |
| | 86 | " | 1136 | Evaporator |
| | 87 | " | 1139 | Settling Tank #2 |

[*] New evaporator vessel and valve location since last field trip.

[**] Flocculator test in settling tank #1.

## APPENDIX 3

### RADIONUCLIDE CONCENTRATIONS IN EVAPORATOR PLANT (EXCLUDING $^{3}H$), $\frac{\mu Ci}{ml}$

| Test No. | Settling Tank | | | Evaporator | | |
|---|---|---|---|---|---|---|
| | Dissolved Material | (Samp.) ( No. ) | Suspended Solids | Dissolved Material | (Samp.) ( No. ) | Suspended Solids |
| | | | $^{22}Na$ | | | |
| 1 | $2.7 \pm 0.6 \times 10^{-7}$ | (3) | ND | $1.6 \pm 0.1 \times 10^{-6}$ | (1) | ND |
| 2 | | | | $1.8 \pm 0.2 \times 10^{-6}$ | (6) | ND |
| 3 | | | | $2.5 \pm 0.5 \times 10^{-6}$ | (11) | ND |
| 4 | | | | $2.4 \pm 0.2 \times 10^{-6}$ | (16) | ND |
| | $2.1 \pm 0.6 \times 10^{-7}$ | (22) | ND | $1.8 \pm 0.1 \times 10^{-6}$ | (20) | ND |
| 5 | | | | $2.4 \pm 0.2 \times 10^{-6}$ | (25) | ND |
| 6 | $1.0 \pm 0.6 \times 10^{-6}$ | (30) | ND | | | |
| | $1.8 \pm 0.8 \times 10^{-6}$ | (33) | ND | | | |
| 7 | $1.1 \pm 0.4 \times 10^{-6}$ | (38) | ND | | | |
| 8 | Sample Lost | (44) | ND | $2 \pm 1 \times 10^{-7}$ | (43) | ND |
| 9 | $7 \pm 2 \times 10^{-7}$ | (47) | ND | $1.8 \pm 0.4 \times 10^{-6}$ | (46) | ND |
| | $6 \pm 1 \times 10^{-7}$ | (50) | ND | $3 \pm 2 \times 10^{-6}$ | (49) | ND |
| 10 | $2.6 \pm 0.5 \times 10^{-6}$ | (53) | ND | $1.4 \pm 0.1 \times 10^{-5}$ | (52) | $1.0 \pm 0.3 \times 10^{-6}$ |
| | $3 \pm 1 \times 10^{-7}$ | (54) | ND | | | |
| 11 | $3 \pm 1 \times 10^{-7}$ | (56) | ND | $1.8 \pm 0.2 \times 10^{-5}$ | (55) | $1.1 \pm 0.6 \times 10^{-6}$ |
| | Sample Lost | (58) | ND | $1.8 \pm 0.1 \times 10^{-5}$ | (57) | ND |
| 12 | $9 \pm 2 \times 10^{-7}$ | (61) | ND | $1.4 \pm 0.2 \times 10^{-5}$ | (60) | ND |
| | $3 \pm 2 \times 10^{-7}$ | (63) | ND | $1.1 \pm 0.1 \times 10^{-5}$ | (62) | ND |
| 13 | $1.3 \pm 0.2 \times 10^{-6}$ | (65) | ND | $1.2 \pm 0.1 \times 10^{-5}$ | (64) | ND |
| | $1.9 \pm 0.3 \times 10^{-6}$ | (67) | ND | $1.5 \pm 0.1 \times 10^{-5}$ | (66) | ND |
| 15 | | | | $4 \pm 1 \times 10^{-6}$ | (72) | ND |
| | | | | $3 \pm 1 \times 10^{-6}$ | (74) | ND |
| 16 | | | | $4 \pm 1 \times 10^{-6}$ | (78) | ND |
| | | | | $5 \pm 1 \times 10^{-6}$ | (82) | ND |
| 17 | | | | $7.8 \pm 0.8 \times 10^{-6}$ | (84) | ND |
| | | | | $9 \pm 1 \times 10^{-6}$ | (86) | ND |

NOTES:
1. ± values indicate analytical error at 2-sigma confidence level.
2. ND - not detectable (sensitivity levels given in Appendix 1 apply generally to in-plant sample analyses).
3. Omission of results for particular samples indicates that the radionuclide was not measurable.

| Test No. | Settling Tank |  |  | Evaporator |  |  |
|---|---|---|---|---|---|---|
|  | Dissolved Material | (Samp.) ( No. ) | Suspended Solids | Dissolved Material | (Samp.) ( No. ) | Suspended Solids |
|  |  |  | $^{54}Mn$ |  |  |  |
| 10 | ND | (53) | $1.3 \pm 0.1 \times 10^{-5}$ | ND | (52) | $6.2 \pm 0.1 \times 10^{-5}$ |
|  | $3.7 \pm 0.4 \times 10^{-6}$ | (54) | $1.7 \pm 0.3 \times 10^{-7}$ |  |  |  |
| 11 | $2.3 \pm 1.3 \times 10^{-7}$ | (56) | $9.6 \pm 0.5 \times 10^{-7}$ | ND | (55) | $2.9 \pm 0.1 \times 10^{-5}$ |
|  | Sample Lost | (58) | $1.0 \pm 0.1 \times 10^{-5}$ | ND | (57) | $5.6 \pm 0.1 \times 10^{-5}$ |
|  | $8 \pm 2 \times 10^{-7}$ | (59) | $2.7 \pm 0.3 \times 10^{-7}$ |  |  |  |
| 12 | ND | (61) | $1.3 \pm 0.1 \times 10^{-6}$ | ND | (60) | $4.9 \pm 0.1 \times 10^{-5}$ |
|  | $7 \pm 2 \times 10^{-7}$ | (63) | $7 \pm 3 \times 10^{-8}$ | ND | (62) | $2.7 \pm 0.1 \times 10^{-5}$ |
| 13 | $5 \pm 3 \times 10^{-7}$ | (65) | $4.1 \pm 0.1 \times 10^{-6}$ | $3 \pm 1 \times 10^{-6}$ | (64) | $2.2 \pm 0.1 \times 10^{-5}$ |
|  | ND | (67) | $6.1 \pm 0.3 \times 10^{-6}$ | $5 \pm 2 \times 10^{-6}$ | (66) | $2.8 \pm 0.1 \times 10^{-5}$ |
| 14 |  |  |  | ND | (68) | $2.2 \pm 0.8 \times 10^{-7}$ |
| 15 | ND | (76) | $1.1 \pm 0.2 \times 10^{-6}$ | ND | (72) | $1.6 \pm 0.4 \times 10^{-6}$ |
|  |  |  |  | ND | (74) | $1.1 \pm 0.4 \times 10^{-6}$ |
| 16 | ND | (80) | $9 \pm 4 \times 10^{-7}$ | ND | (78) | $2.1 \pm 0.3 \times 10^{-6}$ |
|  |  |  |  | ND | (82) | $1.8 \pm 0.8 \times 10^{-6}$ |
| 17 |  |  |  | ND | (84) | $3 \pm 1 \times 10^{-6}$ |
|  |  |  |  | ND | (86) | $2 \pm 1 \times 10^{-6}$ |
|  |  |  | $^{60}Co$ |  |  |  |
| 1 | $7.5 \pm 0.6 \times 10^{-7}$ | (3) | $4.2 \pm 0.3 \times 10^{-8}$ | $3.5 \pm 0.1 \times 10^{-6}$ | (1) | $2.1 \pm 0.1 \times 10^{-6}$ |
| 2 | $2.1 \pm 0.9 \times 10^{-7}$ | (8) | $1.7 \pm 0.4 \times 10^{-8}$ | $3.3 \pm 0.2 \times 10^{-6}$ | (6) | $6.7 \pm 0.2 \times 10^{-6}$ |
| 3 | $2.1 \pm 0.6 \times 10^{-7}$ | (13) | $3 \pm 1 \times 10^{-8}$ | $3.0 \pm 0.2 \times 10^{-6}$ | (11) | $4.8 \pm 0.1 \times 10^{-5}$ |
| 4 | $2.0 \pm 0.2 \times 10^{-7}$ | (18) | $2.2 \pm 0.9 \times 10^{-8}$ | $2.9 \pm 0.2 \times 10^{-6}$ | (16) | $7.0 \pm 0.2 \times 10^{-6}$ |
|  | $6.1 \pm 0.6 \times 10^{-7}$ | (22) | $1.0 \pm 0.7 \times 10^{-8}$ | $3.1 \pm 0.2 \times 10^{-6}$ | (20) | $3.0 \pm 0.1 \times 10^{-6}$ |
| 5 | $2.4 \pm 0.9 \times 10^{-7}$ | (27) | $2 \pm 1 \times 10^{-8}$ | $3.4 \pm 0.1 \times 10^{-6}$ | (25) | $7.7 \pm 0.2 \times 10^{-6}$ |
| 6 | $2.31 \pm 0.03 \times 10^{-4}$ | (30) | $8.0 \pm 0.2 \times 10^{-6}$ |  |  |  |
|  | $3.51 \pm 0.04 \times 10^{-4}$ | (33) | $1.21 \pm 0.02 \times 10^{-5}$ |  |  |  |
| 7 | $8.9 \pm 0.2 \times 10^{-6}$ | (35) | $2.3 \pm 0.2 \times 10^{-6}$ | $1.77 \pm 0.01 \times 10^{-4}$ | (34) | $1.7 \pm 0.1 \times 10^{-5}$ |
|  | $2.07 \pm 0.03 \times 10^{-4}$ | (38) | $7.0 \pm 0.4 \times 10^{-6}$ | $2.6 \pm 0.1 \times 10^{-5}$ | (37) | $3.0 \pm 0.1 \times 10^{-5}$ |
| 8 | $5.6 \pm 0.5 \times 10^{-6}$ | (41) | $1.2 \pm 0.1 \times 10^{-6}$ | $1.55 \pm 0.04 \times 10^{-5}$ | (40) | $7.6 \pm 0.5 \times 10^{-6}$ |
|  | Sample Lost | (44) | $2.0 \pm 0.1 \times 10^{-6}$ | $2.47 \pm 0.04 X 10^{-5}$ | (43) | $1.7 \pm 0.1 \times 10^{-5}$ |

| Test | Settling Tank | | | Evaporator | | |
|---|---|---|---|---|---|---|
| No. | Dissolved Material | (Samp.) ( No. ) | Suspended Solids | Dissolved Material | (Samp.) ( No. ) | Suspended Solids |
| 9 | $5.7 \pm 0.1 \times 10^{-5}$ | (47) | $7.9 \pm 0.4 \times 10^{-7}$ | $2.24 \pm 0.02 \times 10^{-4}$ | (46) | $8.87 \pm 0.04 \times 10^{-5}$ |
| | $7.3 \pm 0.1 \times 10^{-5}$ | (50) | $6.9 \pm 0.8 \times 10^{-7}$ | $3.23 \pm 0.04 \times 10^{-4}$ | (49) | $4.5 \pm 0.1 \times 10^{-5}$ |
| 10 | $1.00 \pm 0.02 \times 10^{-4}$ | (53) | $2.5 \pm 0.1 \times 10^{-5}$ | $4.2 \pm 0.1 \times 10^{-4}$ | (52) | $1.65 \pm 0.02 \times 10^{-4}$ |
| | $4.3 \pm 0.5 \times 10^{-6}$ | (54) | $6.2 \pm 0.5 \times 10^{-7}$ | | | |
| 11 | $3 \pm 2 \times 10^{-7}$ | (56) | $2.0 \pm 0.1 \times 10^{-6}$ | $5.2 \pm 0.1 \times 10^{-4}$ | (55) | $1.86 \pm 0.03 \times 10^{-4}$ |
| | Sample Lost | (58) | $4.9 \pm 0.1 \times 10^{-5}$ | $5.2 \pm 0.1 \times 10^{-4}$ | (57) | $1.35 \pm 0.02 \times 10^{-4}$ |
| | $1.5 \pm 0.3 \times 10^{-6}$ | (59) | $3.5 \pm 0.3 \times 10^{-7}$ | | | |
| 12 | $1.2 \pm 0.1 \times 10^{-5}$ | (61) | $3.7 \pm 0.2 \times 10^{-6}$ | $4.0 \pm 0.1 \times 10^{-4}$ | (60) | $1.12 \pm 0.02 \times 10^{-4}$ |
| | $1.0 \pm 0.2 \times 10^{-6}$ | (63) | $9 \pm 3 \times 10^{-8}$ | $3.8 \pm 0.1 \times 10^{-4}$ | (62) | $5.9 \pm 0.1 \times 10^{-5}$ |
| 13 | $3.0 \pm 0.1 \times 10^{-5}$ | (65) | $2.2 \pm 0.1 \times 10^{-6}$ | $3.2 \pm 0.1 \times 10^{-4}$ | (64) | $4.2 \pm 0.1 \times 10^{-5}$ |
| | $4.3 \pm 0.1 \times 10^{-5}$ | (67) | $9.8 \pm 0.5 \times 10^{-6}$ | $3.4 \pm 0.1 \times 10^{-4}$ | (66) | $3.4 \pm 0.1 \times 10^{-5}$ |
| 14 | $1.9 \pm 0.1 \times 10^{-5}$ | (69) | $3.3 \pm 0.6 \times 10^{-7}$ | $1.7 \pm 0.1 \times 10^{-5}$ | (68) | $2.6 \pm 0.2 \times 10^{-6}$ |
| | $2.1 \pm 0.1 \times 10^{-5}$ | (71) | $2.4 \pm 0.4 \times 10^{-7}$ | $1.8 \pm 0.1 \times 10^{-5}$ | (70) | $7.4 \pm 0.9 \times 10^{-7}$ |
| 15 | $3.0 \pm 0.2 \times 10^{-5}$ | (73) | $1.8 \pm 0.3 \times 10^{-7}$ | $3.07 \pm 0.04 \times 10^{-4}$ | (72) | $6.4 \pm 0.1 \times 10^{-5}$ |
| | $2.8 \pm 0.1 \times 10^{-5}$ | (75) | $1.0 \pm 0.3 \times 10^{-7}$ | $3.15 \pm 0.05 \times 10^{-4}$ | (74) | $5.6 \pm 0.1 \times 10^{-5}$ |
| | $2.9 \pm 0.2 \times 10^{-5}$ | (76) | $1.8 \pm 0.1 \times 10^{-5}$ | | | |
| | $2.2 \pm 0.1 \times 10^{-5}$ | (77) | $1.0 \pm 0.2 \times 10^{-7}$ | | | |
| 16 | $2.5 \pm 0.1 \times 10^{-5}$ | (79) | $9.0 \pm 0.3 \times 10^{-8}$ | $3.40 \pm 0.05 \times 10^{-4}$ | (78) | $1.14 \pm 0.02 \times 10^{-4}$ |
| | $3.1 \pm 0.1 \times 10^{-5}$ | (80) | $2.0 \pm 0.1 \times 10^{-5}$ | $3.37 \pm 0.05 \times 10^{-4}$ | (82) | $1.26 \pm 0.02 \times 10^{-4}$ |
| | $3.3 \pm 0.1 \times 10^{-5}$ | (81) | $1.8 \pm 0.4 \times 10^{-7}$ | | | |
| | $2.6 \pm 0.1 \times 10^{-5}$ | (83) | $1.0 \pm 0.3 \times 10^{-7}$ | | | |
| 17 | $3.4 \pm 0.1 \times 10^{-5}$ | (85) | $5.2 \pm 0.5 \times 10^{-7}$ | $4.4 \pm 0.1 \times 10^{-4}$ | (84) | $5.30 \pm 0.04 \times 10^{-4}$ |
| | $4.6 \pm 0.2 \times 10^{-5}$ | (87) | $3.5 \pm 0.5 \times 10^{-7}$ | $4.6 \pm 0.1 \times 10^{-4}$ | (86) | $5.22 \pm 0.04 \times 10^{-4}$ |
| | | | $^{65}$Zn | | | |
| 10 | ND | (53) | $5 \pm 1 \times 10^{-6}$ | ND | (52) | $1.2 \pm 0.1 \times 10^{-5}$ |
| 11 | ND | (56) | $3.1 \pm 0.8 \times 10^{-7}$ | ND | (55) | $1.2 \pm 0.3 \times 10^{-5}$ |
| | Sample Lost | (58) | $3.3 \pm 0.2 \times 10^{-5}$ | ND | (57) | $1.0 \pm 0.2 \times 10^{-5}$ |
| 12 | | | | ND | (60) | $6 \pm 2 \times 10^{-6}$ |
| | | | | ND | (62) | $5 \pm 1 \times 10^{-6}$ |
| 13 | | | | ND | (64) | $2.0 \pm 0.9 \times 10^{-6}$ |

| Test No. | Settling Tank<br>Dissolved Material | (Samp.) ( No. ) | Suspended Solids | Evaporator<br>Dissolved Material | (Samp.) ( No. ) | Suspended Solids |
|---|---|---|---|---|---|---|
| | | | $^{90}Sr$ | | | |
| 1 | $1.09 \pm 0.01 \times 10^{-4}$ | (3) | $9.2 \pm 0.1 \times 10^{-6}$ | $1.45 \pm 0.01 \times 10^{-3}$ | (1) | not analyzed |
| 2 | $1.8 \pm 0.04 \times 10^{-5}$ | (8) | $3.9 \pm 0.1 \times 10^{-8}$ | not analyzed | (6) | not analyzed |
| 3 | $1.7 \pm 0.04 \times 10^{-5}$ | (13) | not analyzed | $2.24 \pm 0.04 \times 10^{-4}$ | (11) | not analyzed |
| 4 | not analyzed | | not analyzed | $3.84 \pm 0.04 \times 10^{-4}$ | (16) | $1.01 \pm 0.03 \times 10^{-4}$ |
| | | | | $3.82 \pm 0.04 \times 10^{-4}$ | (20) | $4.85 \pm 0.02 \times 10^{-4}$ |
| 5 | not analyzed | | not analyzed | $3.03 \pm 0.02 \times 10^{-4}$ | (25) | not analyzed |
| | | | $^{106}Ru$ | | | |
| 6 | $6.1 \pm 0.9 \times 10^{-5}$ | (30) | ND | | | |
| | $9 \pm 1 \times 10^{-5}$ | (33) | $1.0 \pm 0.4 \times 10^{-6}$ | | | |
| 7 | $2.6 \pm 0.4 \times 10^{-6}$ | (35) | ND | | | |
| | | | | $5.5 \pm 0.3 \times 10^{-5}$ | (34) | ND |
| | $5.8 \pm 0.3 \times 10^{-5}$ | (38) | ND | | | |
| | | | | $7.9 \pm 0.9 \times 10^{-4}$ | (37) | ND |
| 8 | | | | | | |
| | | | | $2.9 \pm 0.3 \times 10^{-6}$ | (40) | ND |
| | Sample Lost | (44) | $7 \pm 3 \times 10^{-7}$ | | | |
| | | | | $4.3 \pm 0.4 \times 10^{-6}$ | (43) | ND |
| 9 | | | | | | |
| | | | | ND | (46) | $1.6 \pm 0.1 \times 10^{-5}$ |
| 10 | $5.9 \pm 0.8 \times 10^{-5}$ | (53) | $8 \pm 2 \times 10^{-6}$ | | | |
| | | | | $2.4 \pm 0.2 \times 10^{-4}$ | (52) | $4.1 \pm 0.5 \times 10^{-5}$ |
| 11 | | | | | | |
| | | | | $2.9 \pm 0.3 \times 10^{-4}$ | (55) | $5 \pm 1 \times 10^{-5}$ |
| | Sample Lost | (58) | $1.2 \pm 0.3 \times 10^{-5}$ | | | |
| | | | | $2.8 \pm 0.2 \times 10^{-4}$ | (57) | $4.7 \pm 0.6 \times 10^{-5}$ |
| 12 | $9 \pm 4 \times 10^{-6}$ | (61) | ND | | | |
| | | | | $2.1 \pm 0.2 \times 10^{-4}$ | (60) | $3.6 \pm 0.6 \times 10^{-5}$ |
| | | | | $2.0 \pm 0.2 \times 10^{-4}$ | (62) | $2.5 \pm 0.4 \times 10^{-5}$ |
| 13 | $1.8 \pm 0.3 \times 10^{-5}$ | (65) | ND | | | |
| | | | | $1.5 \pm 0.2 \times 10^{-4}$ | (64) | $2.1 \pm 0.4 \times 10^{-5}$ |
| | $2.5 \pm 0.6 \times 10^{-5}$ | (67) | ND | | | |
| | | | | $1.6 \pm 0.2 \times 10^{-4}$ | (66) | $3.4 \pm 0.6 \times 10^{-5}$ |
| 14 | | | | | | |
| | | | | $7 \pm 4 \times 10^{-6}$ | (68) | ND |
| 15 | $8 \pm 5 \times 10^{-6}$ | (76) | ND | | | |
| | | | | $7 \pm 2 \times 10^{-5}$ | (72) | $1.6 \pm 0.3 \times 10^{-5}$ |
| | $8 \pm 4 \times 10^{-6}$ | (77) | ND | | | |
| | | | | $4 \pm 2 \times 10^{-5}$ | (74) | $1.5 \pm 0.3 \times 10^{-5}$ |
| 16 | $9 \pm 4 \times 10^{-6}$ | (79) | ND | | | |
| | | | | $6 \pm 2 \times 10^{-5}$ | (78) | $3.0 \pm 0.3 \times 10^{-5}$ |
| | $1.1 \pm 0.4 \times 10^{-5}$ | (80) | ND | | | |
| | | | | $6 \pm 2 \times 10^{-5}$ | (82) | $1.9 \pm 0.5 \times 10^{-5}$ |
| | $1.0 \pm 0.4 \times 10^{-5}$ | (81) | ND | | | |
| 17 | $9 \pm 4 \times 10^{-6}$ | (85) | ND | | | |
| | | | | $1.0 \pm 0.2 \times 10^{-4}$ | (84) | $1.4 \pm 0.1 \times 10^{-4}$ |
| | | | | $9 \pm 2 \times 10^{-5}$ | (86) | $1.3 \pm 0.1 \times 10^{-4}$ |

| Test No. | Settling Tank<br>Dissolved Material | (Samp.)<br>( No. ) | Suspended Solids | Evaporator<br>Dissolved Material | (Samp.)<br>( No. ) | Suspended Solids |
|---|---|---|---|---|---|---|
| | | | $^{125}$Sb | | | |
| 6 | $7 \pm 2 \times 10^{-6}$ | (30) | ND | | | |
| | $7 \pm 2 \times 10^{-6}$ | (33) | ND | | | |
| 7 | $2 \pm 1 \times 10^{-7}$ | (35) | ND | $4.9 \pm 0.6 \times 10^{-6}$ | (34) | ND |
| | $5.9 \pm 0.6 \times 10^{-6}$ | (38) | ND | $8 \pm 2 \times 10^{-6}$ | (37) | ND |
| 8 | Sample Lost | (44) | $2 \pm 1 \times 10^{-7}$ | ND | (43) | $5 \pm 2 \times 10^{-7}$ |
| 9 | | | | ND | (46) | $3.9 \pm 0.2 \times 10^{-6}$ |
| 10 | ND | (53) | $1.2 \pm 0.5 \times 10^{-6}$ | ND | (52) | $4 \pm 1 \times 10^{-6}$ |
| 11 | Sample Lost | (58) | $2 \pm 1 \times 10^{-6}$ | ND | (55) | $9 \pm 3 \times 10^{-6}$ |
| 12 | | | | ND | (60) | $6 \pm 1 \times 10^{-6}$ |
| | | | | ND | (62) | $4 \pm 1 \times 10^{-6}$ |
| 13 | | | | ND | (64) | $2.2 \pm 0.8 \times 10^{-6}$ |
| | | | $^{134}$Cs | | | |
| 1 | $3.1 \pm 0.1 \times 10^{-7}$ | (3) | ND | $1.6 \pm 0.2 \times 10^{-6}$ | (1) | ND |
| 2 | | | | $1.8 \pm 0.4 \times 10^{-6}$ | (6) | ND |
| 3 | | | | $2.4 \pm 0.3 \times 10^{-6}$ | (11) | ND |
| 4 | | | | $2.4 \pm 0.3 \times 10^{-6}$ | (16) | ND |
| | $2.0 \pm 0.1 \times 10^{-7}$ | (22) | ND | $1.9 \pm 0.2 \times 10^{-6}$ | (20) | ND |
| 5 | | | | $2.4 \pm 0.3 \times 10^{-6}$ | (25) | ND |
| 7 | ND | (38) | $2.2 \pm 0.6 \times 10^{-7}$ | | | |
| 8 | | | | $4 \pm 2 \times 10^{-7}$ | (40) | ND |
| | Sample Lost | (44) | ND | $1.3 \pm 0.2 \times 10^{-6}$ | (43) | ND |
| 9 | $5.0 \pm 0.4 \times 10^{-6}$ | (47) | ND | $1.6 \pm 0.1 \times 10^{-5}$ | (46) | $5.4 \pm 0.2 \times 10^{-6}$ |
| | $7.1 \pm 0.2 \times 10^{-6}$ | (50) | ND | $2.6 \pm 0.3 \times 10^{-5}$ | (49) | ND |
| 10 | $4.7 \pm 0.1 \times 10^{-5}$ | (53) | $7 \pm 2 \times 10^{-7}$ | $1.56 \pm 0.02 \times 10^{-4}$ | (52) | $9.7 \pm 0.5 \times 10^{-6}$ |
| | $3.5 \pm 0.4 \times 10^{-6}$ | (54) | ND | | | |
| 11 | $1.6 \pm 0.3 \times 10^{-6}$ | (56) | ND | $2.6 \pm 0.1 \times 10^{-4}$ | (55) | $1.4 \pm 0.1 \times 10^{-5}$ |
| | Sample Lost | (58) | $2.8 \pm 0.4 \times 10^{-6}$ | $2.4 \pm 0.1 \times 10^{-4}$ | (57) | $9.9 \pm 0.7 \times 10^{-6}$ |
| | $1.5 \pm 0.4 \times 10^{-6}$ | (59) | ND | | | |
| 12 | $7.5 \pm 0.5 \times 10^{-6}$ | (61) | ND | $1.9 \pm 0.1 \times 10^{-4}$ | (60) | $6.5 \pm 0.6 \times 10^{-6}$ |
| | $1.4 \pm 0.3 \times 10^{-6}$ | (63) | ND | $1.8 \pm 0.1 \times 10^{-4}$ | (62) | $3.2 \pm 0.4 \times 10^{-6}$ |

| Test No. | Settling Tank: Dissolved Material | Settling Tank: (Samp.) ( No. ) | Settling Tank: Suspended Solids | Evaporator: Dissolved Material | Evaporator: (Samp.) ( No. ) | Evaporator: Suspended Solids |
|---|---|---|---|---|---|---|
| 13 | $2.3 \pm 0.1 \times 10^{-5}$ | (65) | ND | $1.7 \pm 0.1 \times 10^{-4}$ | (64) | $3.0 \pm 0.4 \times 10^{-6}$ |
| | $3.2 \pm 0.1 \times 10^{-5}$ | (67) | ND | $1.9 \pm 0.1 \times 10^{-4}$ | (66) | $2.3 \pm 0.6 \times 10^{-6}$ |
| 14 | $1.4 \pm 0.1 \times 10^{-5}$ | (69) | $5 \pm 2 \times 10^{-8}$ | $2.3 \pm 0.1 \times 10^{-5}$ | (68) | ND |
| | $1.2 \pm 0.1 \times 10^{-5}$ | (71). | ND | $2.3 \pm 0.1 \times 10^{-5}$ | (70) | $6 \pm 2 \times 10^{-8}$ |
| 15 | $1.7 \pm 0.1 \times 10^{-5}$ | (73) | $5 \pm 2 \times 10^{-8}$ | $2.34 \pm 0.03 \times 10^{-4}$ | (72) | $1.6 \pm 0.3 \times 10^{-6}$ |
| | $9.4 \pm 0.7 \times 10^{-6}$ | (75) | ND | $2.35 \pm 0.04 \times 10^{-4}$ | (74) | $1.6 \pm 0.3 \times 10^{-6}$ |
| | $3.0 \pm 0.6 \times 10^{-6}$ | (76) | $2.8 \pm 0.2 \times 10^{-6}$ | | | |
| | $2.6 \pm 0.3 \times 10^{-6}$ | (77) | $2 \pm 1 \times 10^{-8}$ | | | |
| 16 | $5.0 \pm 0.5 \times 10^{-6}$ | (79) | ND | $2.22 \pm 0.04 \times 10^{-4}$ | (78) | $2.9 \pm 0.4 \times 10^{-6}$ |
| | $7 \pm 1 \times 10^{-6}$ | (80) | $5.8 \pm 0.4 \times 10^{-6}$ | $2.07 \pm 0.03 \times 10^{-4}$ | (82) | $4.1 \pm 0.6 \times 10^{-6}$ |
| | $8.0 \pm 0.6 \times 10^{-6}$ | (81) | ND | | | |
| | $4.4 \pm 0.5 \times 10^{-6}$ | (83) | ND | | | |
| 17 | $1.9 \pm 0.4 \times 10^{-6}$ | (85) | $5 \pm 2 \times 10^{-8}$ | $1.83 \pm 0.03 \times 10^{-4}$ | (84) | $7.4 \pm 0.8 \times 10^{-6}$ |
| | $1.3 \pm 0.5 \times 10^{-6}$ | (87) | ND | $1.74 \pm 0.03 \times 10^{-4}$ | (86) | $6 \pm 1 \times 10^{-6}$ |
| $^{137}$Cs | | | | | | |
| 1 | $6.3 \pm 0.1 \times 10^{-6}$ | (3) | $5.9 \pm 0.3 \times 10^{-8}$ | $3.30 \pm 0.03 \times 10^{-5}$ | (1) | $6 \pm 1 \times 10^{-7}$ |
| 2 | $1.3 \pm 0.1 \times 10^{-7}$ | (8) | ND | $3.6 \pm 0.1 \times 10^{-5}$ | (6) | $1.3 \pm 0.2 \times 10^{-6}$ |
| 3 | $1.1 \pm 0.1 \times 10^{-7}$ | (13) | ND | $4.5 \pm 0.1 \times 10^{-5}$ | (11) | $5.9 \pm 0.1 \times 10^{-6}$ |
| 4 | $1.0 \pm 0.3 \times 10^{-7}$ | (18) | ND | $4.9 \pm 0.1 \times 10^{-5}$ | (16) | $8.1 \pm 0.2 \times 10^{-7}$ |
| | $4.3 \pm 0.1 \times 10^{-6}$ | (22) | $2.3 \pm 0.9 \times 10^{-8}$ | $3.88 \pm 0.03 \times 10^{-5}$ | (20) | $4.8 \pm 0.2 \times 10^{-7}$ |
| 5 | $1.0 \pm 0.6 \times 10^{-7}$ | (27) | ND | $4.6 \pm 0.1 \times 10^{-5}$ | (25) | $6.9 \pm 0.2 \times 10^{-7}$ |
| 6 | $8 \pm 1 \times 10^{-6}$ | (30) | $9.2 \pm 0.8 \times 10^{-7}$ | | | |
| | $1.3 \pm 0.1 \times 10^{-5}$ | (33) | $9.5 \pm 0.6 \times 10^{-7}$ | | | |
| 7 | $2.5 \pm 0.5 \times 10^{-7}$ | (35) | $1.0 \pm 0.1 \times 10^{-6}$ | $6.8 \pm 0.3 \times 10^{-6}$ | (34) | $1.4 \pm 0.2 \times 10^{-6}$ |
| | $5.3 \pm 0.4 \times 10^{-6}$ | (38) | $3.2 \pm 0.3 \times 10^{-6}$ | $7.7 \pm 0.6 \times 10^{-6}$ | (37) | $2.6 \pm 0.3 \times 10^{-6}$ |
| 8 | $7.1 \pm 0.5 \times 10^{-6}$ | (41) | $2.0 \pm 0.2 \times 10^{-6}$ | $8.4 \pm 0.4 \times 10^{-6}$ | (40) | $3.8 \pm 0.3 \times 10^{-6}$ |
| | Sample Lost | (44) | $8.4 \pm 0.6 \times 10^{-7}$ | $2.9 \pm 0.1 \times 10^{-5}$ | (43) | $4.9 \pm 0.3 \times 10^{-4}$ |
| 9 | $1.33 \pm 0.02 \times 10^{-4}$ | (47) | $5 \pm 3 \times 10^{-8}$ | $3.65 \pm 0.02 \times 10^{-4}$ | (46) | $4.03 \pm 0.02 \times 10^{-5}$ |
| | $1.63 \pm 0.01 \times 10^{-4}$ | (50) | $1.0 \pm 0.5 \times 10^{-7}$ | $6.28 \pm 0.04 \times 10^{-4}$ | (49) | $2.6 \pm 0.1 \times 10^{-5}$ |
| 10 | $3.44 \pm 0.03 \times 10^{-4}$ | (53) | $4.2 \pm 0.4 \times 10^{-6}$ | $1.28 \pm 0.06 \times 10^{-3}$ | (52) | $6.4 \pm 0.1 \times 10^{-5}$ |
| | $6.5 \pm 0.1 \times 10^{-5}$ | (54) | $9 \pm 2 \times 10^{-8}$ | | | |

| Test No. | Settling Tank: Dissolved Material | Settling Tank: (Samp.) ( No. ) | Settling Tank: Suspended Solids | Evaporator: Dissolved Material | Evaporator: (Samp.) ( No. ) | Evaporator: Suspended Solids |
|---|---|---|---|---|---|---|
| 11 | $5.5 \pm 0.1 \times 10^{-5}$ | (56) | $9.1 \pm 0.5 \times 10^{-7}$ | $2.27 \pm 0.01 \times 10^{-3}$ | (55) | $1.41 \pm 0.02 \times 10^{-4}$ |
|  | Sample Lost | (58) | $7.7 \pm 0.1 \times 10^{-5}$ | $2.30 \pm 0.01 \times 10^{-3}$ | (57) | $9.7 \pm 0.1 \times 10^{-5}$ |
|  | $5.5 \pm 0.1 \times 10^{-5}$ | (59) | $1.6 \pm 0.3 \times 10^{-7}$ |  |  |  |
| 12 | $1.08 \pm 0.02 \times 10^{-4}$ | (61) | $1.4 \pm 0.1 \times 10^{-6}$ | $1.82 \pm 0.01 \times 10^{-3}$ | (60) | $7.0 \pm 0.1 \times 10^{-5}$ |
|  | $5.5 \pm 0.1 \times 10^{-5}$ | (63) | ND | $1.82 \pm 0.01 \times 10^{-3}$ | (62) | $2.8 \pm 0.1 \times 10^{-5}$ |
| 13 | $2.30 \pm 0.01 \times 10^{-4}$ | (65) | $3.5 \pm 0.5 \times 10^{-7}$ | $1.93 \pm 0.01 \times 10^{-3}$ | (64) | $3.7 \pm 0.1 \times 10^{-5}$ |
|  | $3.45 \pm 0.02 \times 10^{-4}$ | (67) | $9 \pm 2 \times 10^{-7}$ | $2.18 \pm 0.01 \times 10^{-3}$ | (66) | $2.8 \pm 0.1 \times 10^{-5}$ |
| 14 | $1.15 \pm 0.02 \times 10^{-4}$ | (69) | $9 \pm 4 \times 10^{-8}$ | $1.74 \pm 0.02 \times 10^{-4}$ | (68) | $3.1 \pm 0.7 \times 10^{-7}$ |
|  | $1.00 \pm 0.02 \times 10^{-4}$ | (71) | $1.2 \pm 0.3 \times 10^{-7}$ | $1.75 \pm 0.03 \times 10^{-4}$ | (70) | $1.3 \pm 0.4 \times 10^{-7}$ |
| 15 | $1.26 \pm 0.03 \times 10^{-4}$ | (73) | $2.2 \pm 0.2 \times 10^{-7}$ | $1.82 \pm 0.01 \times 10^{-3}$ | (72) | $1.4 \pm 0.1 \times 10^{-5}$ |
|  | $7.6 \pm 0.2 \times 10^{-5}$ | (75) | $1.8 \pm 0.3 \times 10^{-7}$ | $1.78 \pm 0.01 \times 10^{-3}$ | (74) | $1.4 \pm 0.1 \times 10^{-5}$ |
|  | $1.9 \pm 0.1 \times 10^{-5}$ | (76) | $2.4 \pm 0.1 \times 10^{-6}$ |  |  |  |
|  | $2.1 \pm 0.1 \times 10^{-5}$ | (77) | $1.5 \pm 0.2 \times 10^{-7}$ |  |  |  |
| 16 | $3.9 \pm 0.1 \times 10^{-5}$ | (79) | $1.3 \pm 0.3 \times 10^{-7}$ | $1.70 \pm 0.01 \times 10^{-3}$ | (78) | $2.6 \pm 0.1 \times 10^{-5}$ |
|  | $3.2 \pm 0.1 \times 10^{-5}$ | (80) | $4.7 \pm 0.1 \times 10^{-5}$ | $1.63 \pm 0.01 \times 10^{-3}$ | (82) | $3.6 \pm 0.1 \times 10^{-5}$ |
|  | $5.7 \pm 0.2 \times 10^{-5}$ | (81) | $2.4 \pm 0.3 \times 10^{-7}$ |  |  |  |
|  | $3.6 \pm 0.1 \times 10^{-5}$ | (83) | $9.0 \pm 0.2 \times 10^{-8}$ |  |  |  |
| 17 | $1.4 \pm 0.1 \times 10^{-5}$ | (85) | $5.5 \pm 0.4 \times 10^{-7}$ | $1.40 \pm 0.01 \times 10^{-3}$ | (84) | $6.2 \pm 0.1 \times 10^{-5}$ |
|  | $1.6 \pm 0.1 \times 10^{-5}$ | (87) | $4.3 \pm 0.4 \times 10^{-7}$ | $1.37 \pm 0.01 \times 10^{-3}$ | (86) | $4.4 \pm 0.2 \times 10^{-5}$ |

$^{226}$Ra

| Test No. | Settling Tank: Dissolved Material | Settling Tank: (Samp.) ( No. ) | Settling Tank: Suspended Solids | Evaporator: Dissolved Material | Evaporator: (Samp.) ( No. ) | Evaporator: Suspended Solids |
|---|---|---|---|---|---|---|
| 9 | ND | (47) | $5 \pm 3 \times 10^{-7}$ | ND | (46) | $8 \pm 1 \times 10^{-6}$ |
|  | $6 \pm 3 \times 10^{-6}$ | (50) | ND |  |  |  |

$^{228}$Ac

| Test No. | Settling Tank: Dissolved Material | Settling Tank: (Samp.) ( No. ) | Settling Tank: Suspended Solids | Evaporator: Dissolved Material | Evaporator: (Samp.) ( No. ) | Evaporator: Suspended Solids |
|---|---|---|---|---|---|---|
| 8 | ND | (41) | $3 \pm 1 \times 10^{-7}$ | ND | (40) | $8 \pm 2 \times 10^{-7}$ |
|  | Sample Lost | (44) | $4.2 \pm 0.6 \times 10^{-7}$ | ND | (43) | $1.3 \pm 0.2 \times 10^{-6}$ |
| 9 | ND | (47) | $9.0 \pm 0.4 \times 10^{-7}$ | ND | (46) | $2.80 \pm 0.02 \times 10^{-5}$ |
|  | ND | (50) | $1.7 \pm 0.2 \times 10^{-6}$ | ND | (49) | $2.1 \pm 0.1 \times 10^{-5}$ |

| Test No. | Settling Tank<br>Dissolved Material | (Samp.)<br>( No. ) | Suspended Solids | Evaporator<br>Dissolved Material | (Samp.)<br>( No. ) | Suspended Solids |
|---|---|---|---|---|---|---|
| | | | $^{241}$Am | | | |
| 10 | ND | (53) | 3.1 ± 0.8 x $10^{-6}$ | ND | (52) | 1.5 ± 0.2 x $10^{-5}$ |
| 11 | ND | (56) | 3.7 ± 0.3 x $10^{-7}$ | ND | (55) | 2.1 ± 0.2 x $10^{-5}$ |
| | Sample Lost | (58) | 2.9 ± 0.2 x $10^{-5}$ | ND | (57) | 1.1 ± 0.2 x $10^{-5}$ |
| 12 | | | | ND | (60) | 1.1 ± 0.2 x $10^{-5}$ |
| 13 | ND | (65) | 2 ± 1 x $10^{-7}$ | ND | (64) | 5 ± 1 x $10^{-6}$ |
| | | | | ND | (66) | 6.9 ± 2.0 x $10^{-6}$ |

## APPENDIX 4. ANNUAL AVERAGE AIR CONCENTRATION NEAR LIMITING RECEPTOR FROM EVAPORATOR STACK DISCHARGE

Annual average concentration for a receptor, within a downwind sector of 22.5-degree width, due to a plume from a single source is estimated by:(1)

$$\overline{\chi} = \frac{2\ Q\ f}{\sqrt{2\pi}\ \sigma_z \mu\ \frac{(2\pi x)}{(16\ )}}\ \exp\left[-\tfrac{1}{2}\ \left(\frac{h}{\sigma_z}\right)^2\right]$$

$\overline{\chi}$ = annual average concentration, μCi/m$^3$
Q = radionuclide discharge rate from stack, μCi/s
f = frequency of wind in receptor sector
$\sigma_z$ = vertical standard deviation of stack plume, m
μ = average wind speed, m/s
x = receptor distance downwind, m
h = stack height, m

The limiting receptor is considered to be an occupant of the residence 800 m NNE of the 10-m-tall stack.

The U.S. Weather Service station closest to Maxey Flats is located at the airport of Lexington, Ky. Their data indicate that the average wind speed, μ, is 3.4 m/s (7.4 mph) and that the wind blows from the SSW at an annual average of 13.1 percent.(2) Because climatological data are lacking, neutral conditions were used to represent average atmospheric stability for determining the value of $\sigma_z$ (27 m). During unstable conditions, dispersion is greater, resulting in lower values of $\overline{\chi}$. Stable conditions produce higher values of $\overline{\chi}$ but since associated wind speeds are low, the site operator is required to dilute wastes being treated. No correction was made for the effect of the higher temperature of the plume relative to air, which increases the elevation at which the plume becomes level, since this additional rise is frequently offset by the rapid downward mixing induced by the evaporator and an adjacent building on passing winds.

$\overline{\chi}$ for the limiting receptor residence is calculated to be $3.3 \times 10^{-6}$ Q.

The individual radionuclide stack discharge rate, $Q_i$, was computed by multiplying the average tank concentrations, given in Section 2.2, by the waste feed rate of 284 ml/s (4.5 gal/min) and dividing by the average plant decontamination factors (DF), discussed in Section 2.6.6. Values of DF, $Q_i$ and the average annual radionuclide air concentration, $\overline{\chi}_i$, for the limiting receptor are as follows:

| Radionuclide | DF | $Q_i$, μCi/s | $\overline{X}_i$, μCi/m$^3$ |
|---|---|---|---|
| $^{3}$H | 1.1 | $5.4 \times 10^{2}$ | $1.8 \times 10^{-3}$ |
| $^{60}$Co | $2.7 \times 10^{2}$ | $2.4 \times 10^{-4}$ | $8.0 \times 10^{-10}$ |
| $^{90}$Sr | $5.8 \times 10^{2}$ | $2.3 \times 10^{-4}$ | $7.6 \times 10^{-10}$ |
| $^{137}$Cs | $4.0 \times 10^{1}$* | $3.1 \times 10^{-2}$ | $1.0 \times 10^{-7}$ |
| $^{238}$Pu | $2.2 \times 10^{5}$ | $1.2 \times 10^{-7}$ | $4.0 \times 10^{-13}$ |
| $^{239}$Pu | $2.2 \times 10^{5}$ | $5.8 \times 10^{-9}$ | $1.9 \times 10^{-14}$ |

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*DF of 40 used due to uncertainty of average value.

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1. Turner, D. B., "Workbook of Atmospheric Dispersion Estimates," USEPA Rept. AP-26 (1970).

2. Leonard, J. H., University of Cincinnati, personal communication (1974).

## APPENDIX 5. ESTIMATED ANNUAL DOSE TO LIMITING RECEPTOR FROM EVAPORATOR STACK DISCHARGE

For $^{3}H$, $^{60}Co$, $^{90}Sr$ and $^{137}Cs$, annual dose to the limiting receptor from inhaling at a standard breathing rate of 23 $m^3$/day evaporator effluent having an annual average concentration, $\overline{X}_i$, was estimated by:

$$\text{Dose, mrem/year} = 23\ \frac{m^3}{\text{day}} \times 365\ \frac{\text{days}}{\text{year}} \times 10^3\ \frac{\text{mrem}}{\text{rem}}\ (\text{DCF})\ \overline{X}_i$$

$$= 8.4 \times 10^6\ (\text{DCF})\ \overline{X}_i$$

Dose conversion factors (DCF), that equate airborne concentrations to dose to receptor organ from radionuclide uptake, are based on the INREM and INDOS Programs(1) which use the recommendations in Publications 2, 6, 10 and 10A of the International Commission on Radiological Protection (ICRP). The limiting receptor and calculation of $\overline{X}_i$ are discussed in Appendix 4.

The DCF's for various critical organs and radionuclide solubility and the estimated annual doses for a $\overline{X}_i$ of $3.3 \times 10^{-6}\ Q_i$ are as follows:

| Radionuclide | Solubility | Critical organ | DCF, rem/µCi | Annual dose, mrem/year |
|---|---|---|---|---|
| $^{3}H$ | sol. | total body | $1.71 \times 10^{-4}$ | 2.6 |
| $^{60}Co$ | sol. | GI tract | $2.13 \times 10^{-2}$ | $1.4 \times 10^{-4}$ |
|  | insol. | lung | $7.44 \times 10^{-1}$ | $5.0 \times 10^{-3}$ |
| $^{90}Sr$ | sol. | bone | $1.11 \times 10^{1}$ | $7.1 \times 10^{-2}$ |
| $^{137}Cs$ | sol | total body | $4.52 \times 10^{-2}$ | $3.8 \times 10^{-2}$ |

Because of the very long effective half-life of $^{238}Pu$ and $^{239}Pu$ in man, radiation doses for these isotopes were calculated on the basis of the average amount delivered annually over a 50-year period from a yearly exposure to levels of $\overline{X}_i = 3.3 \times 10^{-6}\ Q_i$, as follows:

$$\text{Dose, mrem/year} = 23\ \frac{m^3}{\text{day}} \times 10^6\ \frac{\text{pCi}}{\mu\text{Ci}} \times 10^3\ \frac{\text{mrem}}{\text{rem}}\ (\text{DCF})\ \overline{X}_i$$

$$= 2.3 \times 10^{10}\ (\text{DCF})\ \overline{X}_i$$

The average annual DCF's, derived from ICRP recommendations and computed by the Oak Ridge National Laboratory,(2) and estimated doses to the limiting

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receptor are:

| Radionuclide | Solubility | Critical organ | DCF, $\frac{\text{rem/year}}{\text{pCi/day}}$ | Annual dose, mrem/year |
|---|---|---|---|---|
| $^{238}$Pu | sol. | bone | 1.14 | $1.0 \times 10^{-2}$ |
| | insol. | lung | $6.74 \times 10^{-2}$ | $6.2 \times 10^{-4}$ |
| $^{239}$Pu | sol. | bone | 1.24 | $5.4 \times 10^{-4}$ |
| | insol. | lung | $6.32 \times 10^{-2}$ | $2.8 \times 10^{-5}$ |

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1. Killough, G. G. and L. R. McKay, "A Methodology for Calculating Radiation Doses from Radioactivity Released to the Environment," Oak Ridge National Laboratory Report, ORNL-4992 (March 1976).

2. P. S. Rohwer, Oak Ridge National Laboratory, personal communication (1976).

## APPENDIX 6. ENVIRONMENTAL SAMPLES COLLECTED DURING MAXEY FLATS STUDY

| Date sampled | Type of sample | Sample location |
|---|---|---|
| 10/7/74 | Domestic well water | 40, 41, 42, 43, 44 |
| 10/7/74 | Surface water | 3, 9, 15-17, 19, 22-24, 26-31, 34, 35 |
| 10/7/74 | Bed sediment | 3, 26, 30 |
| 11/7/74 | Surface water | 1-6, 8-16, 33-34 |
| 11/7/74 | Bed sediment | 1, 3-16 |
| 3/13/75 | Surface water | 5, 37, 38 |
| 4/29/75 | Domestic well water | 40-44 |
| 4/29/75 | Bed sediment | 20, 21, 25 |
| 6/2/75 | Milk | 46, 48, 49 |
| 6/2/75 | Bed sediment | 12, 17, 18, 27 |
| 8/26-28/75 | Domestic well water | 40-44 |
| 8/26-28/75 | Tomatoes | 40, 41, 44, 48, 51-53 |
| 8/26-28/75 | Grapes | 51 |
| 8/26-28/75 | Cucumbers | 53 |
| 8/26-28/75 | Corn | 48 |
| 8/26-28/75 | Watermelon | 41 |
| 8/26-28/75 | Milk | 41, 46, 47, 50 |

## APPENDIX 7. RADIOCHEMICAL METHODS FOR ENVIRONMENTAL AND TEST WELL SAMPLES

| Sample type | Quantity analyzed | Radionuclide | Method |
|---|---|---|---|
| Water | 1-2 l | γ-emitters (dissolved) | Filtration, evaporation to 100-200 ml, γ-spectrometry.[A] |
| Water | 8-20 l | γ-emitters | Preconcentration by ion exchange (anion and cation), γ-spectrometry. |
| Water | 4-8 ml | $^{3}H$ (HTO) | Distillation, liquid scintillation counting.[B] |
| Water | 1-4 l | $^{90}Sr$ | Precipitation of carbonates, ion exchange separation of Ca and Sr with EDTA.<br>After 2 weeks ingrowth, $^{90}Y$ separated, precipitated and counted with gas flow beta counters.[C] Reference 1 |
| Water | 1-4 l | $^{226}Ra$ | Coprecipitation of Ra with $BaSO_4$, emanation of $^{222}Rn$, scintillation counting of $^{222}Rn$ and daughters.[D] Reference 2 |
| Water | 1-4 l | $^{228}Ra$ | Coprecipitation of Ra with $BaSO_4$, separation of $^{228}Ac$ with yttrium oxalate, beta counting. Reference 3 |
| Water | 1-4 l | $^{238}Pu$, $^{239}Pu$ | Coprecipitation of Pu with Fe(OH), KF fusion, pyrosulfate fusion, solvent extraction, electrodeposition and alpha spectrometry.[E] References 4, 5 |
| Sediment | 1-500 g | γ-emitters | Sediment dried, ground, and sieved through #10 mesh screen, counted by γ-spectrometry. |
| Sediment | 1-10g | $^{90}Sr$ | $^{90}Sr$ leached with boiling 1 N HCl, carbonates precipitated and processed as for $^{90}Sr$ analysis of water. Reference 1 |
| Milk | 4-5 ml | $^{3}H$ (HTO) | Azeotropic distillation of HTO, liquid scintillation counting. Reference 7 |
| Milk | 1 l | γ-emitters | Preconcentration on cation ion-exchange column, gamma-ray spectrometry. Reference 7 |

continued

APPENDIX 7 (continued)

| Sample type | Quantity analyzed | Radionuclide | Method |
|---|---|---|---|
| Milk | 1 l | $^{90}Sr$ | $^{90}Y$ separated after 14 days ingrowth by anion exchange, precipitation as oxalate, and beta counted. Reference 8 |
| Garden produce | ≃ 400 g wet wt. | γ-emitters | Edible parts homogenized with blender, counted by γ-spectrometry. |
| Garden produce | 4-9 g wet wt. | $^{3}H$ (HTO) | Edible parts homogenized with blender, tissue water separated by azeotropic distillation and counted by liquid scintillation. |
| Garden produce | 200 g wet wt. | $^{90}Sr$ | Aliquot of homogenized sample evaporated to dryness, ashed at 450°C, ash processed as soils for $^{90}Sr$ determination. Reference 1 |

Notes:

[A] Gamma Spectrometry - Radionuclides that emit gamma rays were identified and measured with a calibrated gamma-ray spectrometer consisting of a 55- or 85-cc Ge(Li) detector plus a 2048-channel pulse height analyzer.

[B] Liquid Scintillation Counting - Tritium (HTO) was determined by liquid scintillation counting with a Packard Tri-Carb liquid scintillation spectrometer. The scintillation solution was a commercial preparation, Instagel. The samples were prepared by mixing 4 ml or 8 ml of the water sample with an appropriate volume of Instagel to give a total volume of 20 ml. Counting efficiencies were determined by counting standard solutions of tritiated water under the same conditions.

[C] Beta Counters - Strontium-90 and $^{228}Ac$ were counted after chemical separation with low-background (1-2 cpm) end-window Geiger-Mueller detectors. Counting efficiencies were previously determined for the radionuclides of interest as a function of sample thickness.

[D] Radon Counters - Radon-222 plus daughters were counted with a Lucas type ZnS(Ag) scintillation cell and a scintillation counter which consists of a 5.0 cm photomultiplier tube and associated electronics. Additional details regarding the scintillation counter and the calibration of the scintillation cells are given in reference 2.

continued

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APPENDIX 7 (continued)

[E] Alpha Spectrometry - Electrodeposited Pu samples were counted with an alpha-particle spectrometer consisting of an Ortec 400 $mm^2$-diameter silicon surface barrier detector and a 512-channel pulse height analyzer. The detector resolution was approximately 50 keV fwhm at 5.40 MeV. The detector efficiency was approximately 25 percent.

1. Porter, C. R., *et al.*, "Determination of Radiostrontium in Food and Other Environmental Samples," Environmental Science and Technology 1, 745 (1967).
2. Krieger, H. L., "Interim Radiochemical Methodology for Drinking Water," EPA-600/4-75-008/Revised, 16 (1976).
3. Ibid., p. 24.
4. Sill, C. W., U.S. ERDA Health Services Laboratory, Idaho Falls, unpublished procedure (1974).
5. Sill, C. W., Puphal, K. W. and Hindman, F. D., "Simultaneous Determination of Alpha-emitting Nuclides of Radium through Californium in Soil," Anal. Chem. 46, 1725 (1974).
6. Moghissi, A. A., *et al.*, "Separation of Water from Biological and Environmental Samples for Tritium Analysis," Anal. Chem. 45, 1565 (1973).
7. Porter, C. R., "Rapid Field Method for the Collection of Radionuclides from Milk," in Proceedings of the First International Conference of Radiation Protection, Rome, 339 (1966).
8. Porter, C. R., *et al.*, "Determination of Strontium-90 in Milk by an Ion-Exchange Method," Anal. Chem. 33, 1306 (1961).

## APPENDIX 8. THE DOSE CONVERSION FACTOR FOR THE INGESTION OF TRITIUM

The dose conversion factor (DCF) that equates the ingestion of $^3H$ to dose to the total body is based on the INDOS Program,(1) which incorporates the recommendations in Publication 10 of the International Commission on Radiological Protection (ICRP).(2) The DCF for $^3H$, when equilibrium conditions are assumed (the effective half-life is short compared to the exposure time), is computed by

$$DCF = \frac{26.9\ F\ E\ \tau}{M}$$

where

DCF = dose conversion factor, mrem/yr per pCi/day
F = the fractional uptake by the critical organ (total body), 1.0 for $^3H$(2)
E = average effective absorbed energy (MeV) per disintegration, 0.01 for $^3H$(2)
$\tau$ = effective half-life of a radionuclide in the critical organ (total body), 10 days for $^3H$(2)
M = mass of the critical organ in grams, 43,000 g (mass of body water) for $^3H$(2)

Constant value of 26.9 is given by:

$$\frac{3.2\text{x}10^{9}(\frac{\text{dis/day}}{\mu\text{Ci}})\text{x}1.6\text{x}10^{-6}(\frac{\text{erg}}{\text{MeV}})\text{x}10^{-6}(\frac{\mu\text{Ci}}{\text{pCi}})\text{x}10^{3}(\frac{\text{mrem}}{\text{rem}})\text{x}365(\frac{\text{days}}{\text{yr}})}{100(\text{erg/g tissue/rad})\text{x}1.0(\text{rad/rem})\text{x}0.693}$$

Substituting these parameters into the above equation, a DCF of $6.2 \times 10^{-5}$ mrem/yr per pCi/day is obtained for $^3H$. Multiplying this factor by the average daily intake of $^3H$ yields the average annual dose in mrems to the total body.

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(1) Killough, G. G. and McKay, L. R., "A Method for Calculating Radiation Doses from Radioactivity Released to the Environment," Oak Ridge National Laboratory Rept., ORNL-4992 (March 1976).

(2) Report of Committee 4 of the International Commission on Radiological Protection, "Evaluation of Radiation Doses to Body Tissues from Internal Contamination Due to Occupational Exposure," ICRP Publication No. 10, Pergamon Press, Oxford (1967).

## APPENDIX 9. ACKNOWLEDGMENTS

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